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3D PRINTED FOOTWEAR DESIGN

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by Seyed Behrad Ghodsi

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Abstract:

This project is focused on developing a range of design concepts for printable footwear. The idea is to build a consumer based system, which reduces labor for manufacturing and provides ease of access to new products for consumers.

Experts predict that everyone will have a 3D printer at home in the near future and people will be able to design and make objects on their own (Dale Nicholls 2014).

Currently the 3D printing technology is not developed enough for non-designer use. By developing a range of stylish footwear design concepts, the production process would speed up and the costs of production would be reduced. This idea will allow everyone to use prepared designs and print usable products on their personal 3D printers.

This footwear will be designed in a way that lets a regular 3D printer make it without fail. In addition, the final CAD files of products will be accessible to 3D printer owners.

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CHAPTER 1.
BACKGROUND OF STUDY

1. Introduction

I believe that fashion expresses how we live our lives, and that products express the story of their creation. I believe that one day the most aesthetically up-to-date fashion would be created entirely by robots, without any human interference. That was a flash-forward story of Atosaa and my prime motivation to work in 3D printing.

2. Purpose of Study

Based on my interest in fashion design and the potential in this field I started to study its market and tried to find something more of a product than a mere fashion element. I decided to design shoes, a product that could both satisfy my desire for fashion industry and besides, it could be 3D printed!

I am fascinated by technology and suppose that a designer should be aware of all new technologies, anticipate their role, and apply them to his/her product.

3D printing is believed by experts to be the leading manufacturing method in future. This almost new phenomenon and a world of possibilities it made available, motivated me to choose it as my method of production.

CHAPTER 2.
FASHION

1. What is fashion?

Fashion is a worldwide phenomenon. People express themselves, their character and feelings through fashion. It subtly reflects the culture in society. Fashion is a true combination of art and technology. Fashion business is of a complex nature and collects a wide range of talents and skills to deliver products to consumers in the optimum quality (Hines and Bruce 2007, 169).

Figure 1 - Fashion drawing study

It’s quite challenging to define fashion. For some it’s an art or part of their lifestyle. It can be a way to introduce yourself to the world, or maybe a way to hide from it. But for sure is a medium for our visual expression.

The fact is fashion is not just about the clothes we choose to wear, it is about our beliefs and world view. Simply fashion is the maintaining pattern in clothing and behavior.
But who determines what fashion is? What is considered fashionable and what is not?

Fashion Designers

Classic fashion brands - Chanel, Prada and Gucci - are called “haute couture”, which means “high fashion” in French. These designers decide the path for trends. Their designs might be radical or unusual for everyday wear, but the theme is changed into something more appropriate to wear (khorshidchehr 2012)

Media

So many times fashion trends are inspired by characters on television shows such as Carrie Bradshaw in “Sex and the City”. The edgy designs in this show will touch the way you want to fashion your style. (khorshidchehr 2012)

Celebrities

You may have not known UGGs if Kate Hudson and Jessica Simpson were not spotted wearing them. That is a true story. (khorshidchehr 2012)

Musicians

The most influential individuals in fashion trends are musicians. A classic example is Elvis, everyone in 50s wanted to dress like him. So as heavy metal in 80s, Axl Rose made bandanas popular again while some other musicians spread out big, rocker hair. (khorshidchehr 2012)

2. Fashion markets and fashion marketing

The main elements in fashion industry are textile, garments and footwear; others may include items like perfumery, food, automobiles, housing and beauty products. Fabrics, home furnishing and upholstery as textiles are fashionable items too. However, fashion can be applied to a broad range of goods. A quick view to modern lifestyle shows consumerism completely depends on fashion trends and is heavily affected by it (Hines and Bruce 2007, 2).

Worldwide trade in clothing and textile is about $350 billion. In 2004 these industries covered 7 percent of total exports. During 1997 and 2004 clothing and textile exports rose 5.9 and 3 percent, respectively. This doesn't draw a distinction between different countries on how they rely on these industries. For example it's 80 percent of total exports in Bangladesh but 11.9 percent in China (Hines and Bruce 2007, 2).

In China employment figures in textile and closing manufacturing rose from 14 million in 1995 to 19 million in 2004. There are over 40 million people employed in this industry around the world. Although figures are different in every country, but women form almost 70 percent of all employees (Hines and Bruce 2007, 2).

The global employment in clothing has decreased from 14.5 million to 13 million during 1990 to 2000 due to industrialization. The same thing happened in textile business, workers decreased from 19.7 in 1990 to 13.5 million in 2000 (Hines and Bruce 2007, 2).

Nonetheless these two industries are a pivot point in economy of developing countries.
In table 1.1 you can see the employment rate in clothing manufacturing in different countries and its magnificence among other industries (Hines and Bruce 2007, 2).

2.1 The footwear business and advertising

The footwear industry has begun a limited business but later expanded into a successful industry. In this chapter the elements accelerating this industry such as advertising expenses, global market shares, and worldwide consumption will be discussed. Today, people spend more on purchasing due to economic growth and increased buying power. Advertising and good commercials also play a big part for the business, building a relation between the company and the consumer. It is now among the company politics to reserve a remarkable budget for advertising to promote themselves and stay ahead of the competition (Luximon 2013, 254).

2.1.1 The footwear industry

Footwear has risen into a complicated and ambitious business, with China being its biggest producer and exporter universally. The industry works with different materials to produce various and diverse shoes, covering all demands. The importance and popularity of footwear is a crucial concept for consumers in developed countries. Footwear industries nowadays play an important part in idustryalized countries. Domestic markets in unindustrialized countries for locally created footwear have also developed moderately, due to the outflow of urbanized country exports. These improvements have led to the setting up of relatively considerable, capital-intensive plants. Local companies with restricted access to technical information have implemented manufacturing techniques similar to those in “turn-key” industries, using technologies suitable for the local region, which generally means a comparatively low scale of production (Luximon 2013, 254).

2.1.2 The global footwear market

The footwear industry has a competitive business with both key and small players in search for commission. Several companies all over the world spend over $ 1.0 billion selling footwear. In the chart 13 you can see the footwear market in 2011 with Asia –Pacific including China being the third most acknowledged area after Europe and America. China has had the most successful and the biggest footwear industry for the past 15 years. Yet some famous footwear brands such as Adidas, Nike, Reebok, control the market, the financial and the technological aspects of the industry (Luximon 2013, 255).

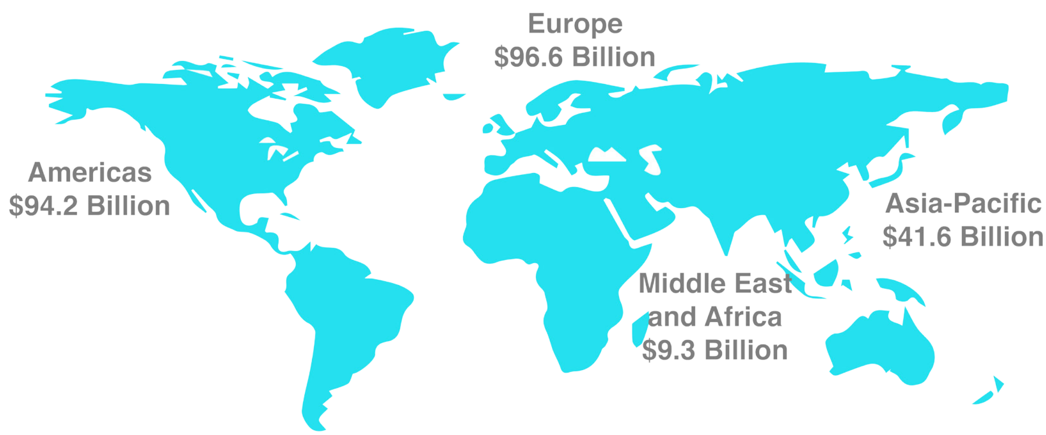


Chart 1 - Global footwear market in 2011

Cogitamus Consulting (2009) stated that the global footwear retail market growth was raised by 2% in 2007, rising from $ 189.3 billion to $ 192.3 billion in 2008. There was a 4% annual growth for 2004-2008. Chart 2 shows the global footwear retail market from 2004-2001. There was a 3% estimated growth from 2007 to 2011, according to Marketline (Luximon 2013, 255).

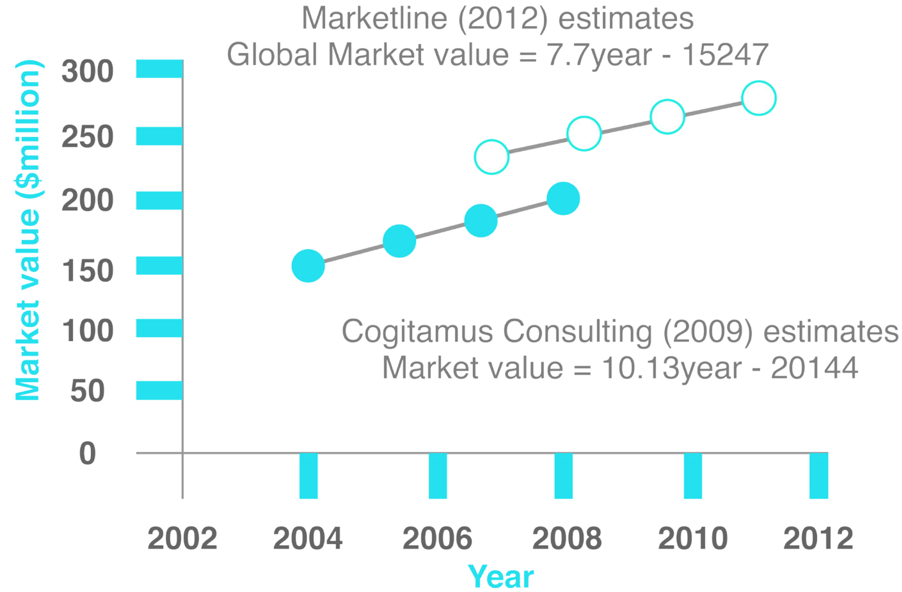


Chart 2 - Global footwear retail market 2004 - 2008 (in billion $)

From chart 3 we can see China being the biggest exporter to the US, supplying more than 87% of US footwear imports. According to Cogitamus Consulting, Vietnam also has replaced Brazil as the second biggest footwear supplier to the US since 2006 (Luximon 2013, 256).

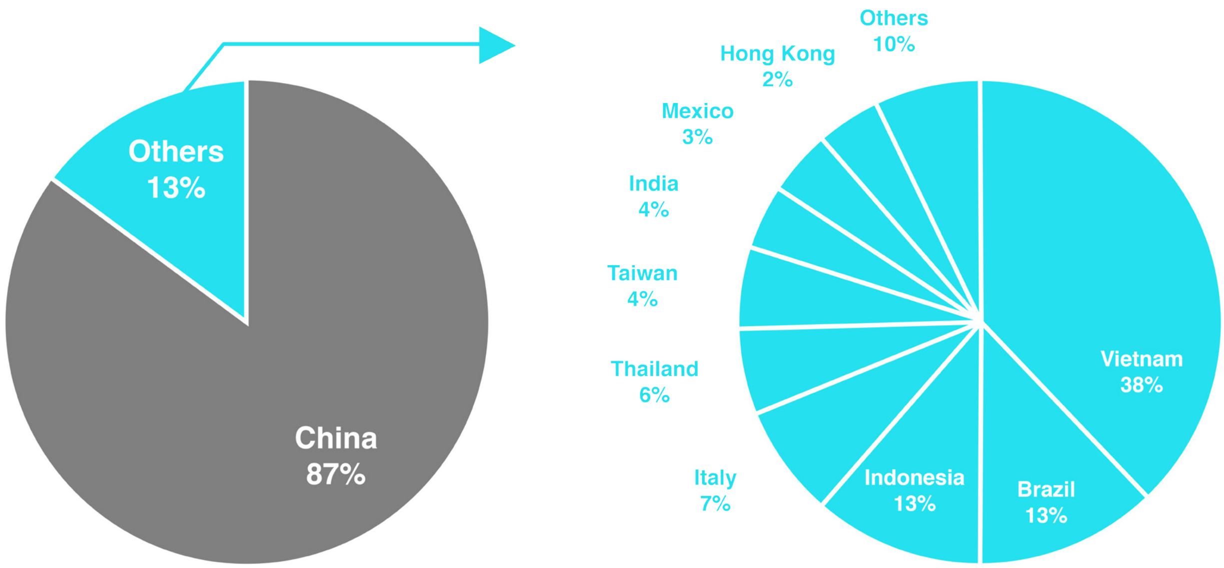


Chart 3 - Footwear suppliers to the US in 2008 (by volume)

The US is the first market potential for footwear with 34% of the share, Asia is number two with 32% followed by Europe staying at number three with 25% of the share. Middle East and Africa has 4% and the rest, 1%. chart 4 shows the global footwear market from 2001 to 2011 (Luximon 2013, 257)

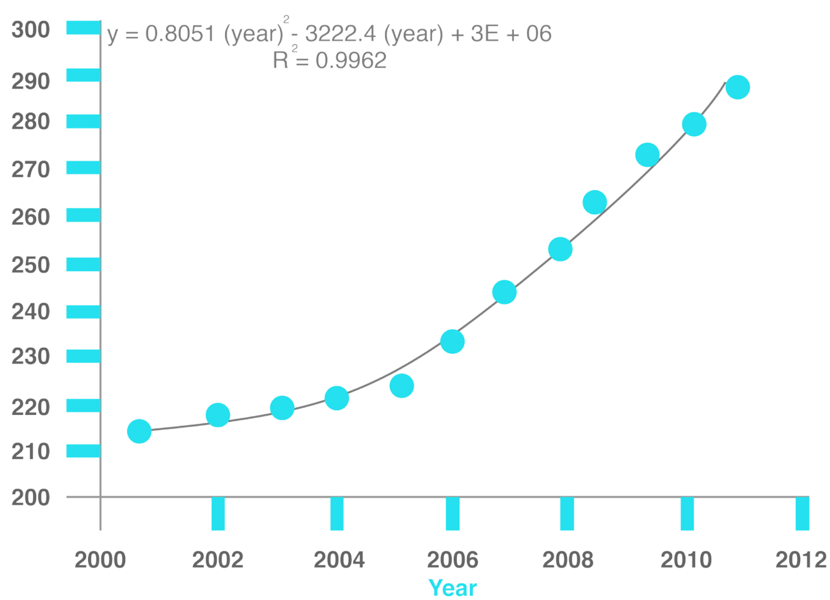


Chart 4 - Market potential for footwear

2.2 Global consumption

The footwear industry is developing fast due to population growth and high standards of living.

2.2.1 Consumers expenditure on footwear

In accordance with U.S Bureao of Labor Statistics (www.bls.gov), the average annual of footwear consumption for each consumer in 2007 is 8% higher from the money spent on footwear in 2006. Generally footwear spendings has increased up to $ 300 since 2001 which has a parallel relation with the economic growth. Marketing and fashion experts believe that today, consumers care for industries belief systems and policies so it's important for the companies to build an emotional connection with them to make them feel satisfied (Luximon 2013, 257).

2.2.2 Style trends in footwear

The footwear business is achieving a new level with personalization and customization of shoes. Shoes that focus on characteristics, personalities, and beliefs of the individual buyer. There are shoes that not only resolve the needs but also have a say in fashion such as Adidas. Adidas now has modified platforms, like mi Adidas and mi Original. mi Adidas, launched in 2007 allows consumers to custom-design their own running shoes (Luximon 2013, 257).

CHAPTER 3.
FOOTWEAR

1. What are high heels?

Footwear which is high-heeled (that mostly we abbreviate as high heels or simply heels) are footwear that raise the heel of the wearer's foot significantly higher than the toes. If both the heel and the toes are raised at the equal amounts, as in a platform shoe, we do not technically consider it a high heel; however, there are also platform shoes that are high-heeled. With high heels we would have the aesthetic illusion of longer, more slender legs.

Figure 2 - Types of high heels

As stated by high-fashion shoe websites like Jimmy Choo and Gucci, we consider a “low heel” less than 2.5 inches (6.4 centimeters), whilst those heels which are between 2.5 and 3.5 inches (6.4 and 8.9 cm) are considered “mid heels”, and anything higher than that is considered a “high heel”. It appears that the apparel industry have a simpler view; the term “high heels” covers heels that range from 2 to 5 inches (5.1 to 12.7 cm) or more. Extremely high-heeled shoes, like those exceeding 6 inches (15 cm), properly speaking, are no longer considered apparel but rather something akin to “jewelry for the feet”. People wear them for display or just enjoyment.

Although high heels are usually known to be worn by women and girls, there are shoes designed for both genders that have elevated heels, including cowboy boots and Cuban heels. In previous ages, high heels were also worn by men (Wikipedia 2009).

2. Why people wear high heels?

Dealing with feet for a living without encountering some of the miserable side effects of wearing high heels — such as foot pain, corns, and calluses is impossible. The American Podiatric Medical Association studied 503 women about their high-heel habit (nailsmag 2009).

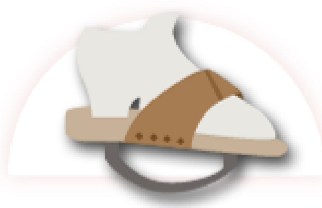
Chart 5 - Why people wear high heels

3. Revolution of high heels

Images can go beyond more the words, especially when it comes to analyzing the evolution of design that is relevant to a specific product. Below you can see a record of amazing high heels design pieces through time.

1189

The Knights of Richard the Lion-hearted adopted the style to wear curved pointed toe, high heel shoes to keep their feet in stirrups when riding horses.



500-1500

During the Middle Ages and time of the bubonic plague, men and women began to wear high wooden soles, or pattens, on cheap shoes to stay clean on the dirty streets.

1533

The first mention of modern high heels was recorded when worn by the bride and Italian noble-woman Catherine d'Medici in French Court as she introduced Renaissance Italian fashion to France.

Figure 3 - High heels timeline 1/2

1660

King Louis XIV's shoemaker Nicholas Lestage crafted fashionable high heels that depicted a decorative battle scene with a 5 inch heel, often called the "Louis" heel.

1500-1600

Chopine shoes (originally created in Turkey) were popularized in France, Spain, and Italy in this century. Shoe heights hit up to 24 inches.

1745

Petit Madame de Pompadour popularized high and narrow shoe heels in the court of King Louis XV.

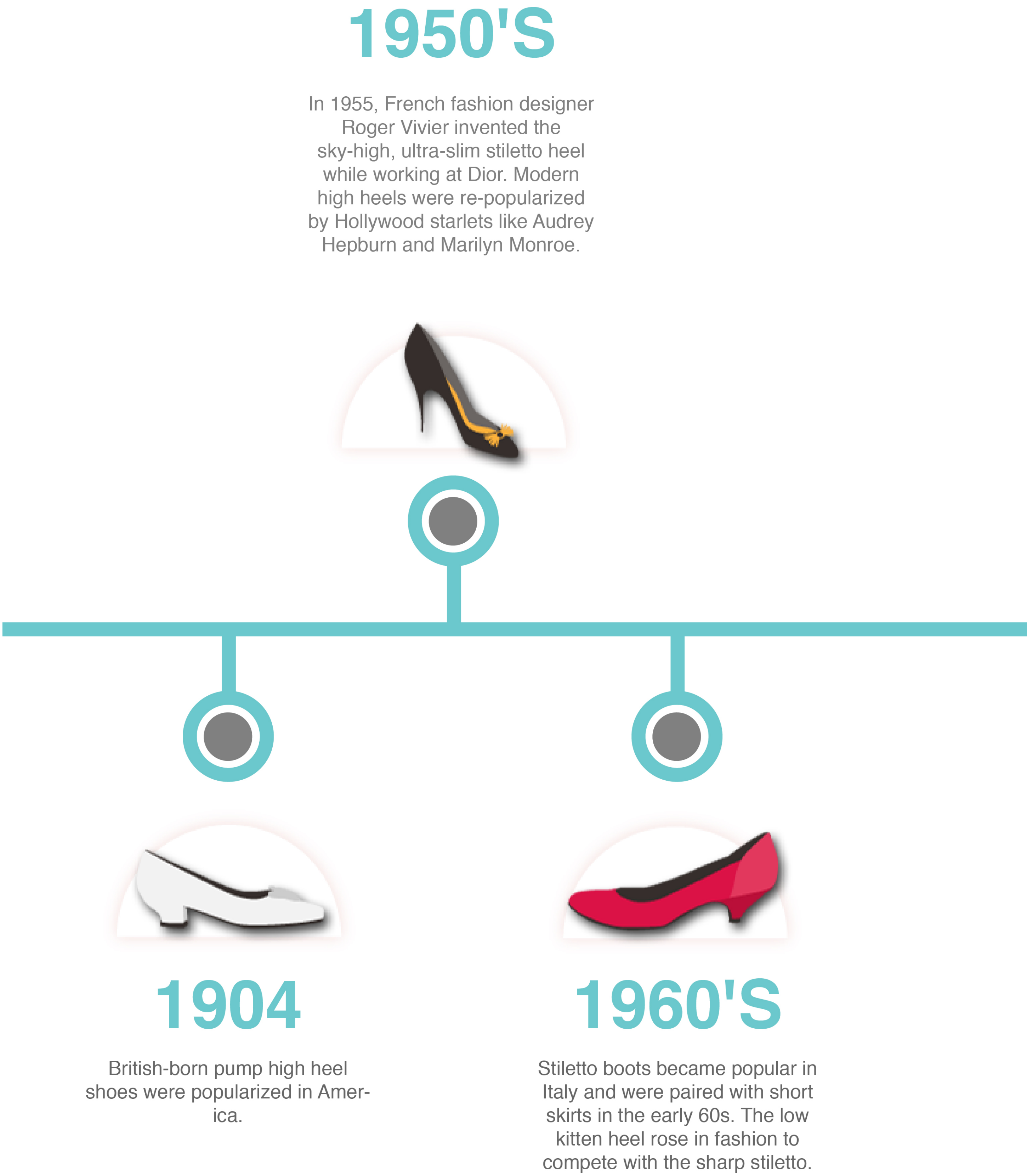


Figure 4 - High heels timeline 2/2

1980'S

Manolo Blahnik revitalized sky-scraper stiletto heels in avant-garde styles; popular TV shows like Dynasty and Dallas brought back trademark high heels for every occasion.

1970'S

Move over, stiletto, and make way for chunky platform shoes! The 1970s were unique since high heel platforms were again worn by both men and women at the disco..

1990'S

Christian Louboutin could also be accredited with the return of stiletto fashion in the 1990s/2000s, known by his famous red-bottomed high heels.

3. Types of high heels

Here you are provided with different types of high heel styles, a description of their features and also the different occasions that people use high heel styles.

STILETTO

Inarguably one of the most popular high heels of all time, known for its pencil-thin, dagger-like heel to lengthen even the shortest legs.

WEDGE

A solid heel throughout the length of the foot to add height in a casual setting; may be preferred by women who aren't comfortable in uber-tall stilettos.

PEEP-TOE

A high heel shoe with a twist, a peep-toe heel merges pump and sandal styles to show "a little bit of toe" with every step.

Figure 5 - Types of high heels

PLATFORM

A throwback to the 1970s that adds all-over height in varying styles, including pumps and wedges.

SANDALS

These open shoes are more casual than close toed shoes.

PUMPS

classic tapered heel with a pointed toe that has been popular for over a century; a standard pump heel is slightly thicker than a stiletto heel.

5. High heels anatomy

In shoes you can considerably find fewer main parts than what is the foot itself, but each is still designed to function with the movement of the foot. Prior to start designing a shoe it is important to realize the function of each component. It is also helpful to identify each part by its industry standard name.

At the time of introducing your design ideas to factories or developers, It can be very useful. Although a shoe is composed of numerous, independently manufactured parts they must still work together as a dynamic whole. Experts from completely separate locations make and design heels and shoes. The stitching of the upper sections can even be obtained. So a shoe factory is just the place where all these parts are assembled. In other words factories do not produce components or raw materials of shoes (Choklat 2012, 34).

Here is some information about the most important parts of a shoe:

Upper:

The Upper part is any part on the shoe above the sole. It is made up of pattern pieces that are sewn together. Commonly upper material is leather, but they can be made of textiles too.

Lining:

To keep the internal parts of the upper in place and support them, the lining is very important. Most common materials used for lining are textile, pigskin and calfskin (Choklat 2012, 34).

Toe box:

For maintaining the height and shape of the front end of the shoe a toe box is very useful. It’s a semi rigid thermoplastic material piece that is heated in order to mold the shape of the toe area. The most elegant shoes can have a leather toe box (Choklat 2012, 34).

Heel counter:

A heel counter is necessary to maintain the shape of the heel cup area and to hold the heel of the foot in place (Choklat 2012, 34).

Sock lining:

The surface that touches the bottom of the foot is created by sock lining. Either the footbed or the insole is covered with sock lining, and consists of a piece of leather or fabric where they place usually the branding (Choklat 2012, 34).

Shank:

The supporting bridge between heel and the ball of the foot is the shank. It is attached to the insole board and commonly it is a steel strip but shanks can be made up of different materials like wood, nylon and even leather (Choklat 2012, 34).

Insole:

Structure and shapes to the bottom of the shoe are supplied by insole. It is the main component to which the upper can be attached to. It is made up of insole board and shank that are glued together. The insole board is made up of cellulose board or a composite material (Choklat 2012, 34).

Outsole:

The bottom part of the shoe that touches the ground is the outsole. Various materials can be used in making outsole depending on the price and the end use of the shoe.

Heel:

The heel is made of hard material, commonly hard plastic and then is covered in leather. Heel is attached to the sole. A heel cap is the small plastic bottom tip of women's shoe-heel. It is designed in order to be replaced after wear and tear. (Choklat 2012, 34)

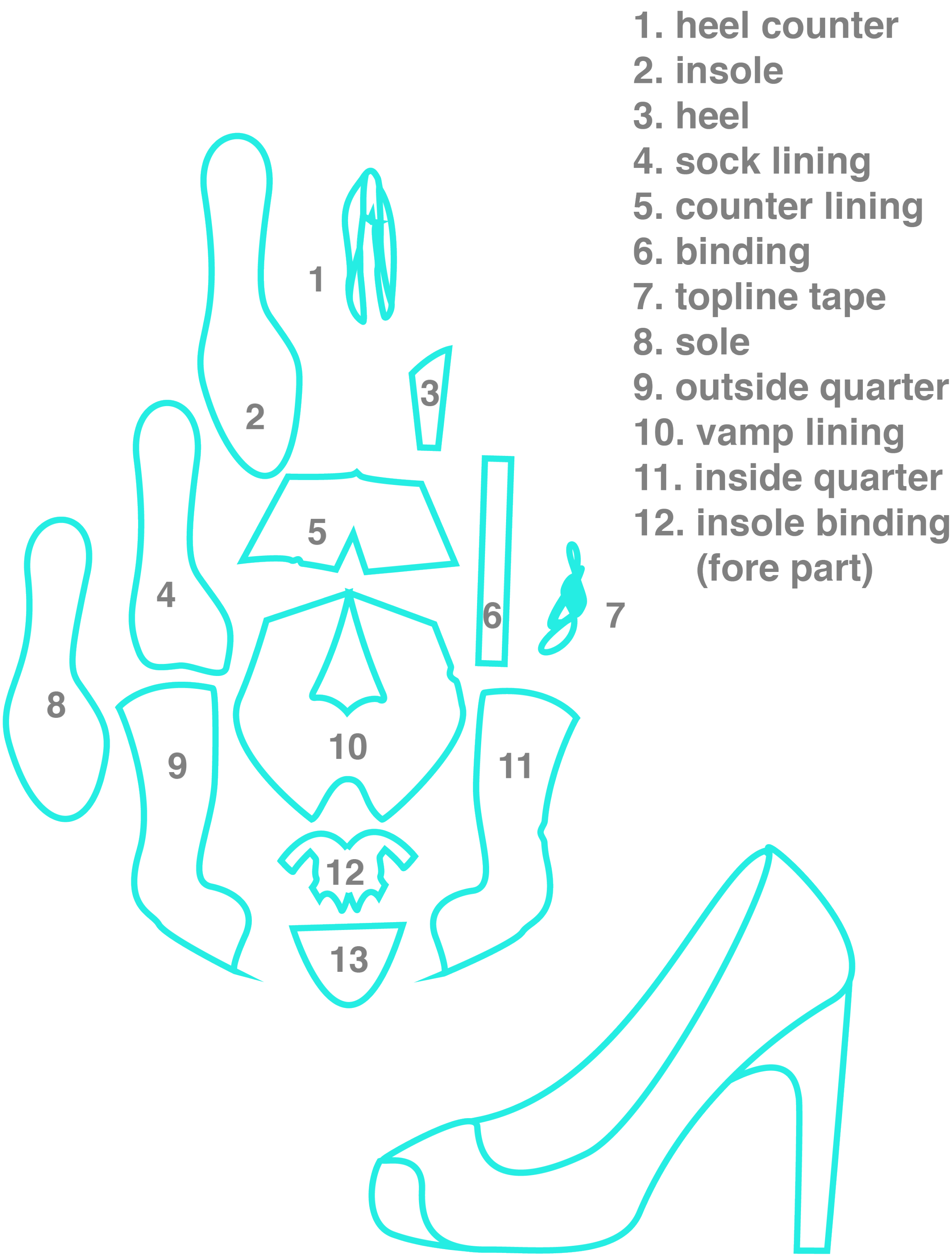


Figure 6 - High heels anatomy

6. The environmental impact of footwear and footwear materials

The impact that the environment has on a product throughout its life-cycle is an important issue. Products such as footwear that are complex need so many different manufacturing processes and materials, and all these materials and processes have an effect on the overall environmental impact of the product. In this part we will discuss the effect of the footwear materials, production process and disposal on the environment and also will focus on the life-cycle estimation as a means of measuring this impact (Luximon 2013, 266).

6.1 Footwear and footwear materials

Although we can name several categories of footwear, the focus of this chapter is only on shoes. The components that you read the following are common to any style or category of shoe (Luximon 2013, 267):

(i) upper part- All element above the shoe's sole

(ii) Lower part - The whole bottom of the shoe (sole, insole and outsole)

(iii) Grindery - This part consists of other items which can be attached to the upper and lower parts of the shoe just like eyelets and toe puffs.

Depending on the different parameters and factors, shoes can be classified into many different categories. This classification can be done by factors like gender (e.g. men's or women's shoe) or the purpose that it is used (e.g. sport shoes). Another way of classification is relevant to this chapter is classifying based on the material used to produce the upper part of the shoe. By this kind of classification, shoes can be classified into leather-based, textile-based and rubber or plastic-based products (Luximon 2013, 267).

In manufacturing of a shoe many different materials may be used. The most common materials used to produce the upper part are canvas, leather, PVC and polyurethane.

The common material for sole are leather, TPR (thermoplastic rubber), polyurethanes, TUP (thermoplastic polyurethanes) and EVA (Luximon 2013, 267).

There is a broad list of elements that are counted as grindery, such as nails, eyelets, shanks, laces, velcro/catches, threads, foams (padding), textile backers and linings, heels and toe cap reinforcements.

6.2 Importance of the environmental impact of footwear and footwear materials

As stated by the 2011 World footwear Yearbook,20 billion pairs of footwear were produced worldwide in 2010(World Footwear,2011).In manufacturing of footwear plenty of raw and subsidiary materials and also a lot of resources like water and energy are used. At the same time in production process we come to a large amount of waste that requires to be disposed or recycled. At the end, the 20 billion pairs of footwear will also be torn and there will be the time for them to be disposed of. All of these issues show the importance of the need to measure and discuss the environmental effects of footwear (Luximon 2013, 268).

To analyze this effect, studying the process of the production and consumption in footwear is very important. In production trend presently, materials such as textiles, leather, rubber and many different types of synthetics are being used. On the average, near 40 different kinds of materials are used in the production of a pair of shoes (Weib, 1999).Each and every one of the materials used are unrivaled, not only in the physical and functional features, but also in their environmental effect during the whole of the life cycle of the product (Luximon 2013, 268).

6.3Conclusion

According to this, I will consider these problems during design process in order to reduce the environmental effect, excess costs such as costs for disposal, energy and also will try to design something more compatible with the environment and also a recyclable production.

CHAPTER 4.
FOOT

1. Foot Anatomy

Though feet are small, our whole weight is on them and they help us balance our bodies. They are under pressure for prolonged periods of time. Either standing or walking, we spend around 33% of our life time on our feet. Just like other limbs and parts of the body, especially the moving parts, our feet are full of nerve ending which communicate with the rest of the body. So a well-designed shoe not only is a good looking one but also a shoe that makes your feet and therefore your mobility comfortable (Choklat 2012, 30).

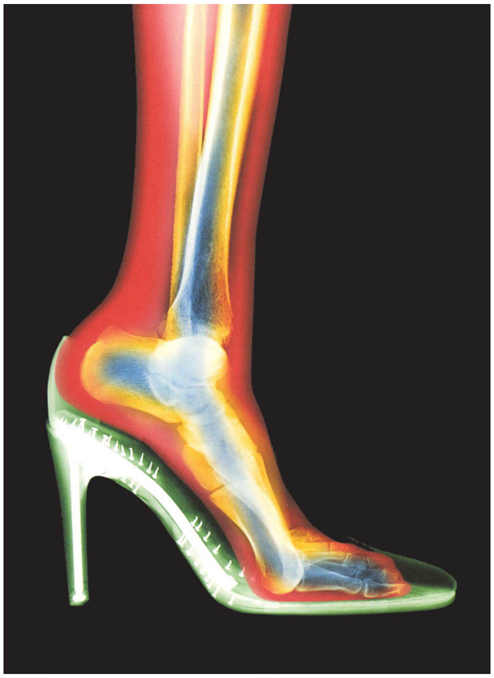


Figure 7 - Foot anatomy x-ray photo

This shows with following the curvature of the foot a silhouette is shaped that is the definition of the contemporary look of sexy footwear.

2. Basic section of the foot

A shoe designer should be completely familiar with basic sections in a foot and based on the anatomy of the foot I will try to regard the sensitive parts of the foot and consider them while designing.

The basic sections of the foot are ankle, heel, arch, ball, toes and instep.

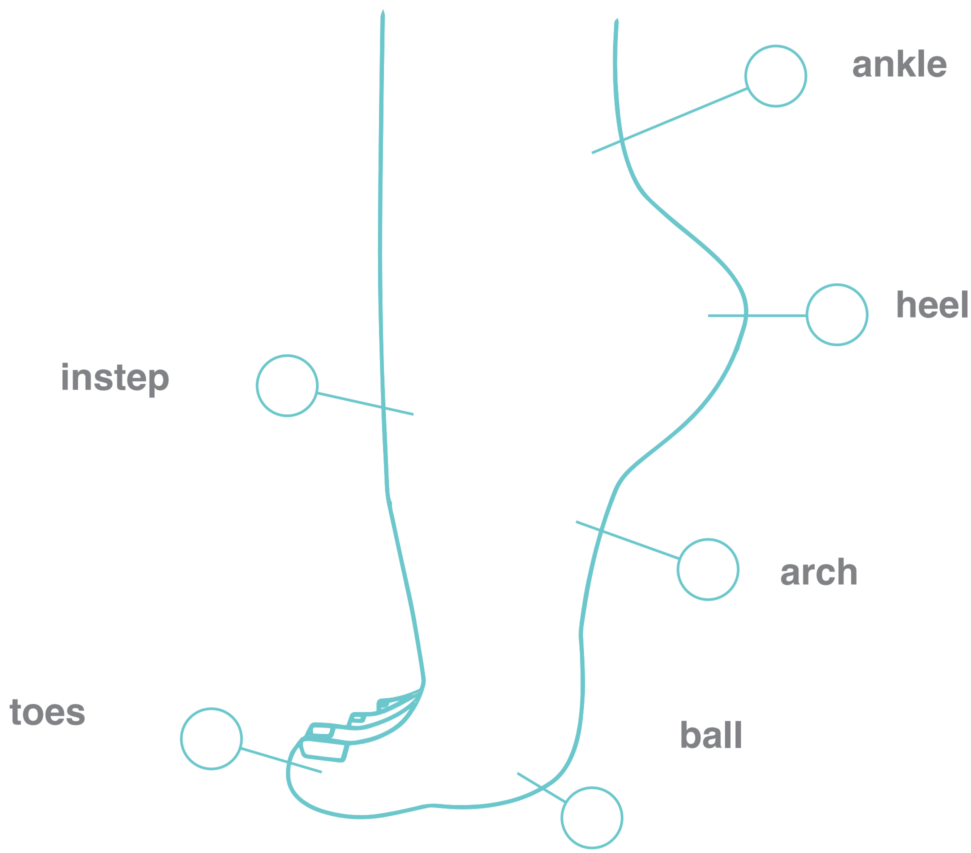


Figure 8 - Basic sections of foot

3. Anatomical components of a foot

-26 bones

-33 joints

-Ligaments

- Tendons

– Blood vessels

– Nerves

– Skin, nails, and tissue

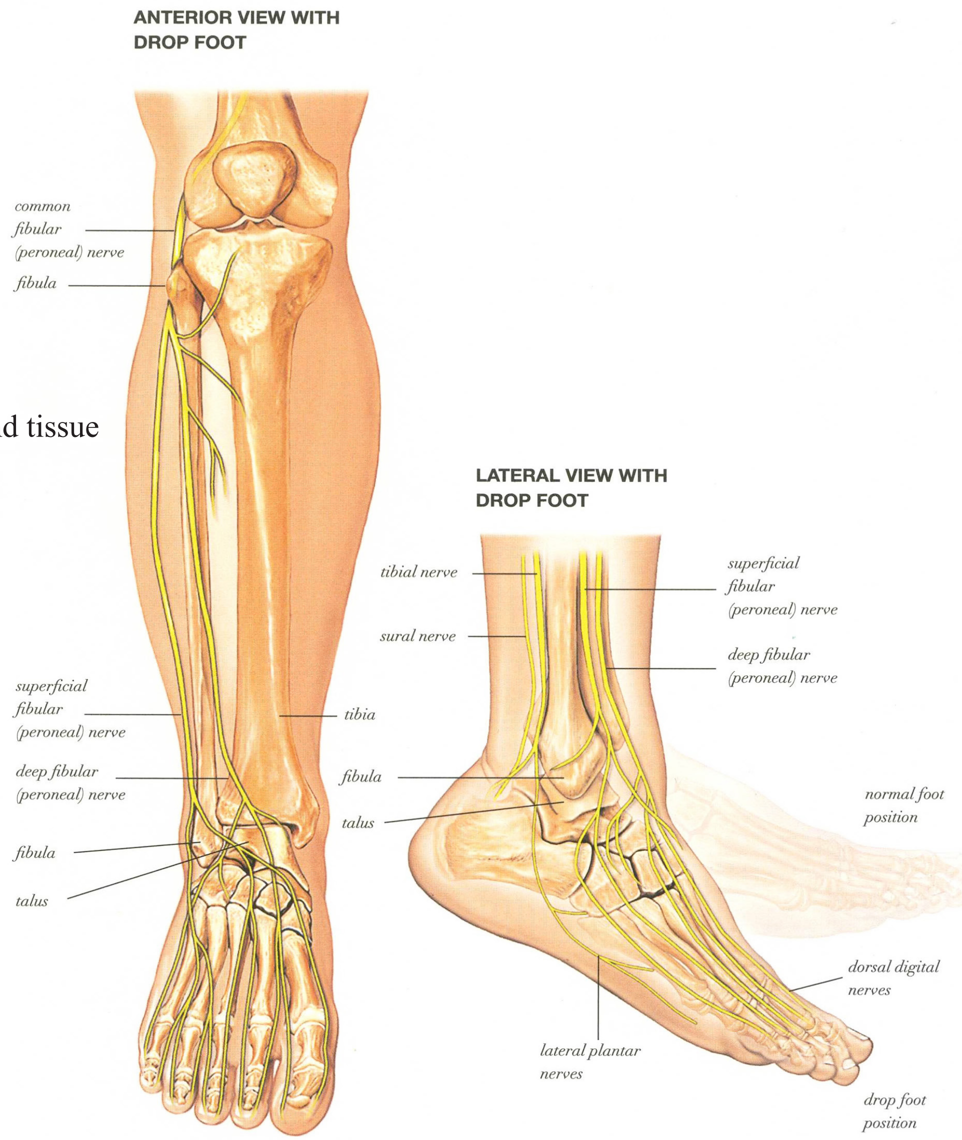


Figure 9 - Anatomical components of a foot

In designing shoes the incredible complicated anatomy of the foot and the various bones, muscles and ligaments must be considered.

4. Foot Scanning

According to the method I had in mind to design my final product, I was exploring a solution to scan the foot and to design a shoe that covers all sensitive parts of different costumers with unique foot styles.

I searched for a way to analyze the user's foot so I was able to redesign the shoes with costumers' demands by 3D printing technology.

In my research I confronted different concepts that were able to scan the foot and figure out the users' foot qualities such as foot size, foot's pressure amount, or foot's arche.

This technology is usually designed for orthotic for putting it into the shoes and make them more comfortable. But with the need I defined, and 3D printing technology, this system can help my concept. Here I describe a sample of this concept with its properties:

4.1 I Step Digital foot scan:

The i Step Foot Scanning System from Aetrex measures the foot size, arch type and pressure points by the usage of digital scanners and pressure sensors in less than 30 seconds. The pressure-plate technology existed before for diabetics but Aetrex took it further, permitting medics and people to know the feet data for a healthier life (Mather 2011).

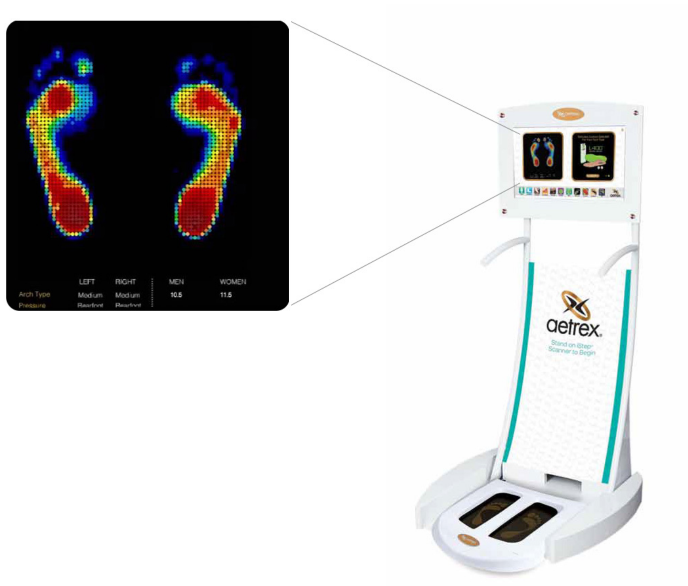


Figure 10 - i Step digital foot scan

The Aetrex i Step digital foot scanning system's pressure sensor technology contains 1,326 infrared LEDs. It also includes, receptors to assure actual measurement and analysis, assisting to relieve foot pain sufferers and anyone looking to be more aware of footwear choices(Mather 2011).

The pressure sensor technology that is used by i Step involves 3,744 gold-plated barometric sensors that measure the pressure exerted by your foot every 0.25 cm2. Then, 1,326 infrared LEDs and receptors are activated and aligned every half-millimeter to ensure accurate measurement and analysis. Then i Step uses the measurements to recommend the exact shoe size and proper orthotic insoles that will help relieve common foot problems like arch pain, arthritis, corns and heel pain, along with giving advice to anyone who wants to be comfortable in their shoes (Mather 2011).

5. Common foot problems

It is necessary to know the causes of foot problems to provide the perfect answer for people. The contributions of footwear design in alleviating the common problems must be acknowledged.

Some of the most common foot problems

In this section I have searched for common foot problems as a result from wearing inappropriate shoes. I tried to decrease the difficulties and problems a considerable amount in the final design by defining the reasons.

The list below which includes the problems and their acquisition percentage is the result of the research by college of Podistry which surveyed 2000 British and 60 podiatrists and chiropodia-trists.

I will also explain these problems briefly (Reilly 2013).

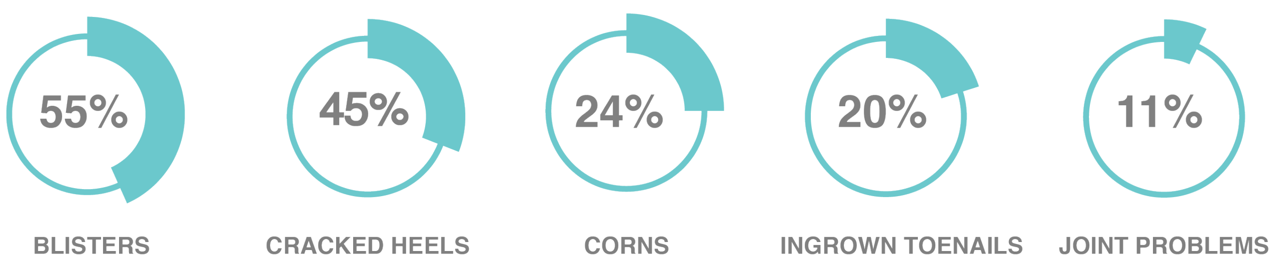


Chart 6 - Most common foot problems

5.1 Blisters:

A blister is a small bubble on the skin filled with serum or plasma and is usually caused by friction, burning, freezing, chemical exposure or other damages (Wikipedia 2005).

5.2 Cracked heel:

Cracked heels or heel fissures are a common foot problem experienced by many people. It is a sign of lack of attention rather than just overexposure or lack of moisturizing. In most cases the problem is merely a nuisance and unattractive to look at, however when the cracks or fissures become deep and it is left untreated, standing, walking, or any pressure placed on the heel can be painful (Epodiatry n.d.).

5.3 Corns:

A corn (or clavus, plural clavi or clavuses) is a distinctively shaped callus of dead skin that usually occurs on thin or glabrous (hairless and smooth) skin surfaces, especially on the dorsal surface of toes or fingers. They can sometimes occur on the thicker palmar or plantar skin surfaces (Wikipedia 2004).

5.4 Ingrown toenails:

An ingrown toenail also referred to as onychocryptosis or unguis incarnatus is when the edges or corners of a toenail grow into the soft tissue of the toe and pieces it. It is a common condition which can be quite painful, causing swelling, redness, and occasionally infection (Cole 2015).

5.5 Joint Problems:

Each foot has 26 bones and over 30 joints. Most people suffer from one or more of these joints. The pain usually co-occurs with soreness, redness, injure, firmness. Joint pain may be caused by trauma, infection, inflammation, arthritis, bursitis, gout, or structural foot problems but is healed with rest and restrained walking. Usage of non steroidal anti- inflammatory drugs (NSAIDs), like

like ibuprofen, and ice help decreasing the pain. Custom orothotic devices may also be prescribed to decrease the pain. Yet a foot and ankle surgeon is best able to notice the result of joint pain and heal it (Foothealthfacts 2015).

CHAPTER 5.
3D Printing

1. What is 3D Printing?

“3D printing” is a conversational phrase for a group of technologies known as additive manufacturing. 3D printing is a process of making three dimensional solid objects from a digital file. The creation of a 3D printed object is achieved using additive processes. In an additive process an object is created by layering down successive layers of material until the entire object is created (Warner et al. 2014, 9).

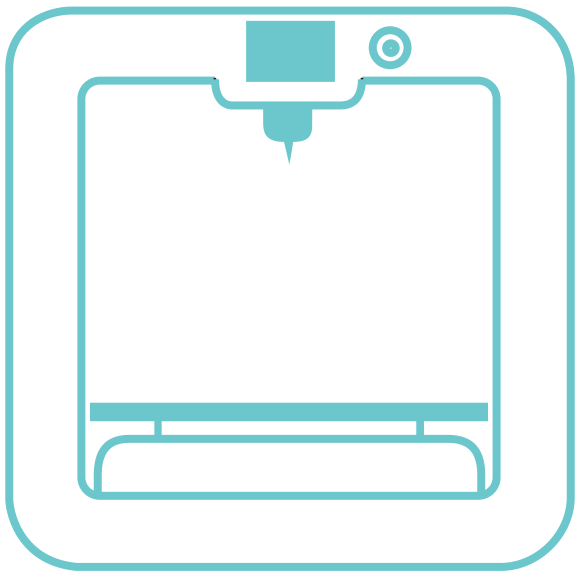


Figure 11 - 3D printer illustration

Additive manufacturing has a different manufacturing process rather than traditional manufacturing techniques such as milling, sawing, and cutting. It includes removing or decreasing material from a solid block to accomplish the wanted shape. There are a lot of limitations on the shapes that can be achieved by a subtractive manufacturing tool since it needs a clear path to the area where material has to be removed. The phrase “subtractive manufacturing” has recently been used to explain the more traditional methods and to set the part from the newer paradigm of additive manufacturing (Warner et al. 2014, 9).

3D printing is also known as rapid prototyping, rapid manufacturing, stereolithography, layer manufacturing, desktop manufacturing, and free form fabrication. Although all of these phraseology is fading due to having the term “3D printing” the most popular and common in the mainstream and industry (Warner et al. 2014, 9).

1.1 How does it work?

All 3D prints begin with a digital 3D model of the sample you wish to design. This varies from something you have downloaded from a website to buying it from a marketplace or modelling it from scratch using 3D design software. After the needed checks to guarantee that the model is printable or “watertight”, a last step is required to interpret the 3D model into a language that the 3D printer understands. The model is cut into horizontal layers and each layer is converted into x and y coordinates for the print-head. The printer defines the coordinates and print out the layers, fusing the material to shape a physical object (Warner et al. 2014, 9).

You can print with various resolutions in most processes. The resolution describes the layer thickness and outline accuracy of each layer. Even with high resolution the layers are never invisible which gives the object a some what crinkled surface. In most samples, the rough surface of a finished print is smoothed out using post-processing techniques like sanding, waxing, and polishing (Warner et al. 2014, 9).

2. History of 3D Printing

Below is a collection of memorable 3D printing technology through time.

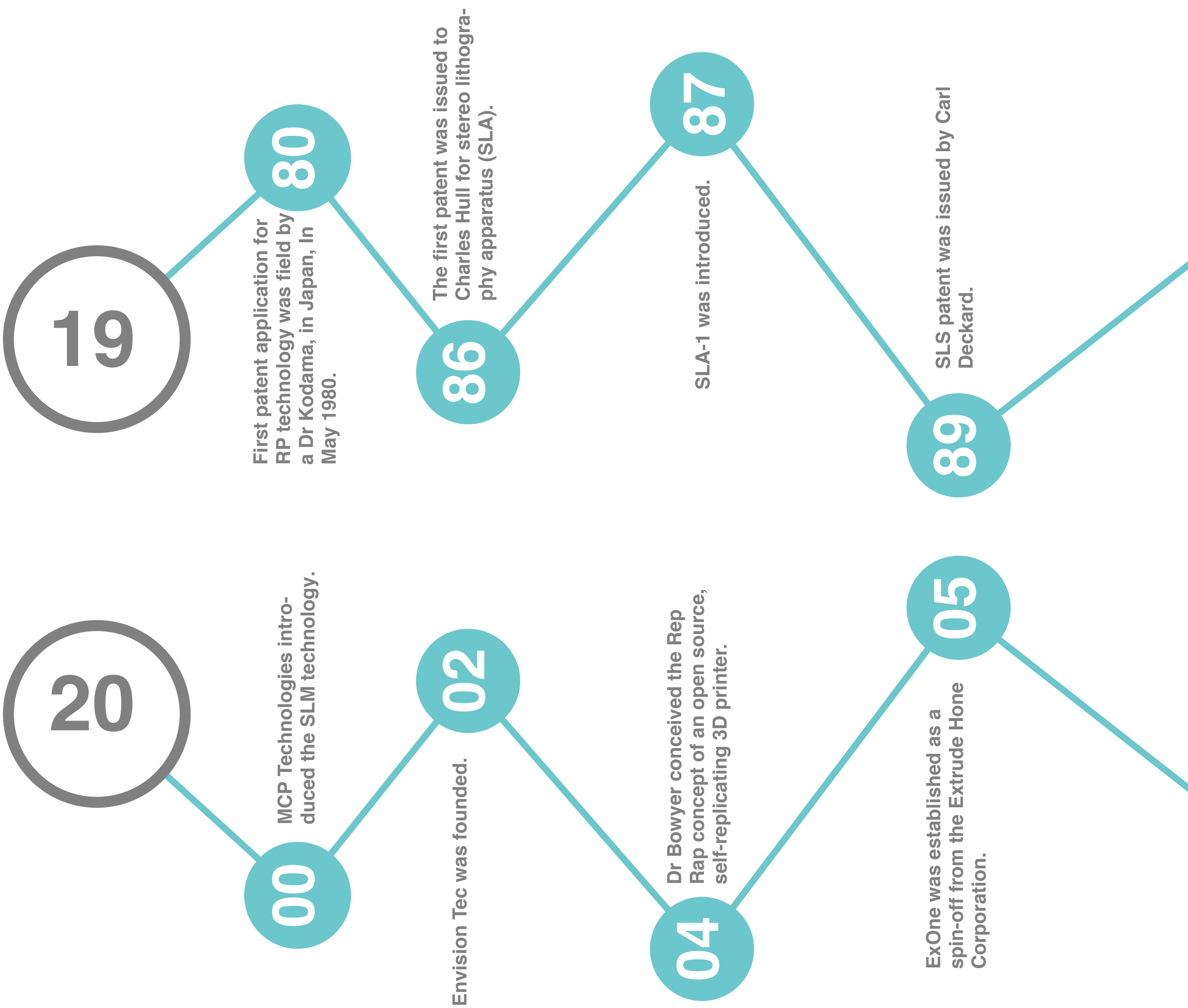
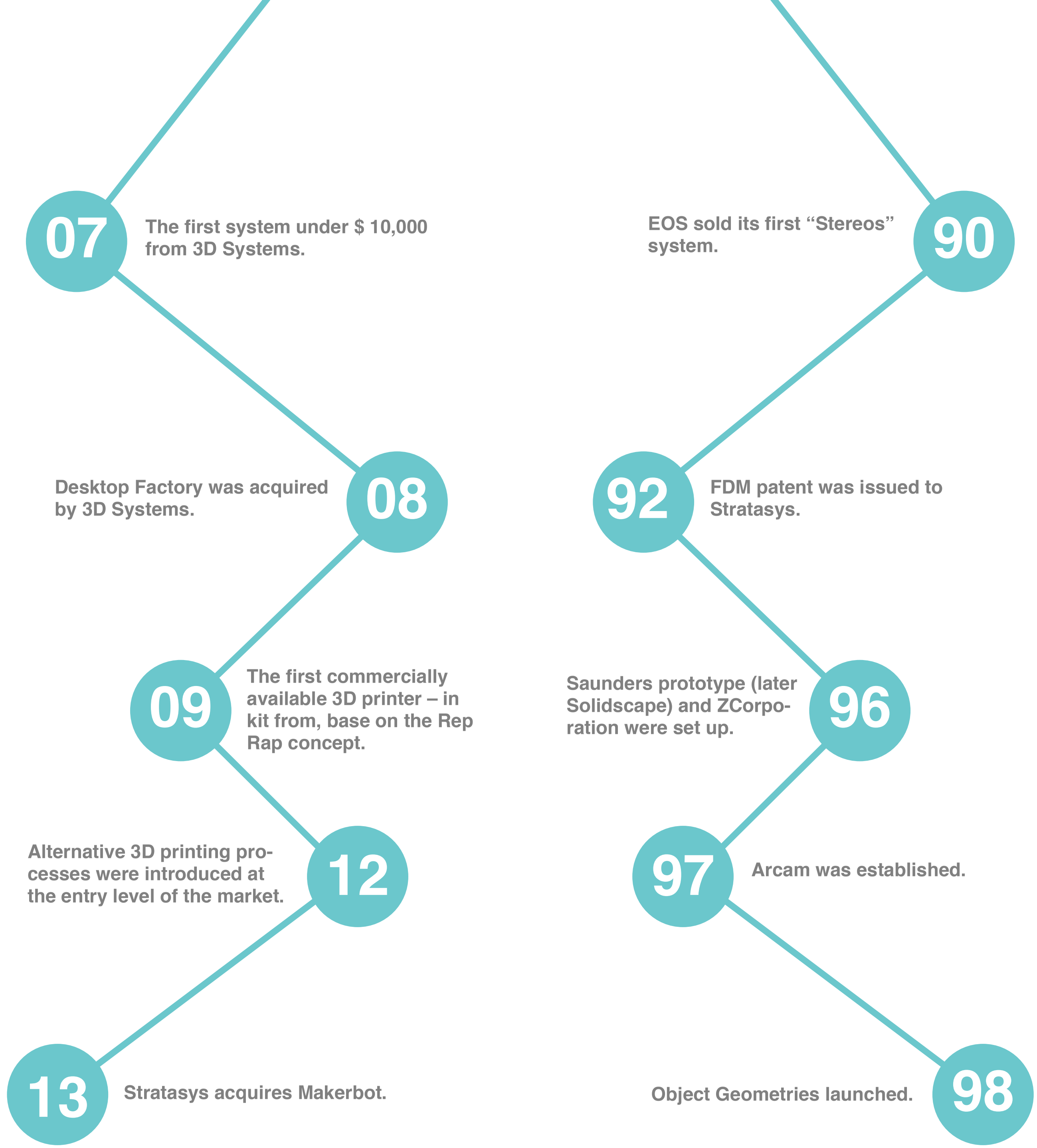


Figure 12 - 3D printer timeline


90
EOS sold its first “Stereos” system.
92
FDM patent was issued to Stratasys.
96
Saunders prototype (later Solidscape) and ZCorporation were set up.
97
Arcam was established.
98
Object Geometries launched.
07
The first system under $ 10,000 from 3D Systems.
08
Desktop Factory was acquired by 3D Systems.
09
The first commercially available 3D printer – in kit from, base on the Rep Rap concept.
12
Alternative 3D printing processes were introduced at the entry level of the market.
13
Stratasys acquires Makerbot.

3. 3D Printing Benefits & Value

3D printing brings many benefits which traditional manufacture methods are incapable of.

3.1 Customization

3D printing allows for a considerable amount of customization- the capability to individualize and characterize the products within the requirements and necessities. A real beneficial point of 3D printers is that numerous products are able to be manufactured simultaneously at no additional cost (3dprintingindustry 2014).

3.2 Complexity

The appearance of 3D printing has seen a proliferation of products which have different stages of complication that can't be made physically with any other methods. This made artists and designers achieve impressive visual effects and also has helped the industry by producing much lighter and stronger products than their previous methods. Among their remarkable usage is the aerospace industry where these issues are the most important (3dprintingindustry 2014).

3.3 Tool-Less

One of the most cost, time, and labor intensive stages of product improvement process is tool producing. Industrial 3D printing can decrease the tool production demand a great amount, therefore it will result in great time, money, labor save and manufacturers would be interested in them. Furthermore, because of the complicated advantages mentioned above, products and components can be designed specifically in order to prevent assembly requirements with intricate geometry and complicated features further eliminating the labor and costs associated with assembly processes (3dprintingindustry 2014).

3.4 Sustainable / Environmentally Friendly

3D printing is known to be an energy-efficient technology which provides environmental efficiencies in the manufacturing process by using up to 90% of the standard materials which produces less waste.

Additionally, 3D printers are appearing to be great insurance in terms of achieving a local manufacturing model in which products are produced on demand in the place where they are required __ removing huge inventories and unsustainable engineerings for shipping mass products globally (3dprintingindustry 2014).

4. 3D Printing processes

3D printers process in two different categories. The first one prints objects by using a print-head to bind a layer of material while the second one uses a print-head to deposit the material by itself on the previous section of dismissed material.

Nowadays the mainstream usage of a 3D printer process is the trio of SLS (selective laser sintering), FDM (fused deposition modeling), SLA (stereolithography).

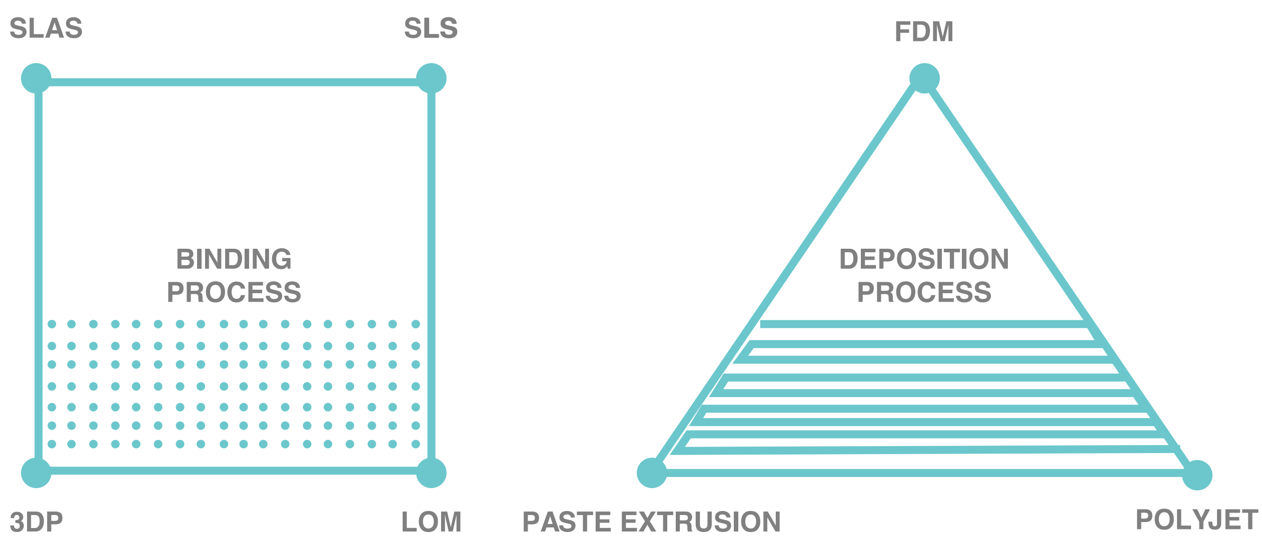


Figure 13 - 3D printing processes

4.1 Binding Processes

Binding processes function by spreading a whole layer of powdered, liquid, or sheet material across the total build volume before a tool head draws and binds the contours of the object. An entire layer of material is deposited each cycle, so the printed objects is supported by unused build material at all times, which mitigates the need of bonus generated support structures – except in the case of stereolithography (Warner et al. 2014, 10).

4.1.1 Stereolithography (SLA)

SLA is the oldest form of 3D printing in which uses photopolymerization. Photopolymerization is also a traditional technique used in the traditional paper printing industry to produce embossed flexographic printing plates. In this process a computer controlled moving laser beam is used to build up the required structure, layer by layer from a photopolymer. A photopolymer is a liquid polymer that solidifies when exposed to light (Warner et al. 2014, 11).

4.1.2 Selective Laser Sintering (SLS)

During Selective Laser Sintering a high power laser melts and bonds a powder material to form a solid, three-dimensional object. A layer of sinter powder is deposited by a roller on the build platform. After each laser pass, the platform lowers and a new layer of powder is spread over the top of the structure from container on the side (Warner et al. 2014, 11).

4.1.3 Inkjet Powder Printing (3DP)

Inkjet Powder Printing uses a similar powder bed approach to SLS. An Inkjet printhead moves across a bed of powder, selectively depositing a liquid binding material. The whole process looks acquainted with printing on paper (Warner et al. 2014, 12).

4.1.4 Laminated Object Manufacturing (LOM)

Laminated Object Manufacturing printers produce objects by assembling and laminating any thin layers onto each other. The cross segments are cut from the layers with a cutter. As the printing process is over the samples will be removed from the solid block of material into which it is embedded (Warner et al. 2014, 13).

4.2 Deposition Processes

In deposition process a liquid ejects from a nozzle in the print-head which layer by layer it deposits the material in a pattern on a platform. This stands opposite to binding processes in which the model is embedded in the material. In deposition process the model stands freely on the build platform which requires traditional support structures for hanging geometries (Warner et al. 2014, 13).

4.2.1 Fused Deposition Modeling (FDM)

Fused deposition modeling printers use a thermoplastic filament which is heated to its melting point and then extruded, layer by layer, to create a three dimensional object. During printing, the materials take the form of plastic threads or filaments, which are unwound from a coil and fed through an extrusion nozzle (Warner et al. 2014, 14).

4.2.2 Paste Extrusion

Paste extrusion is a process in which anything can be pushed out of the nozzle. In Paste extrusion process, instead of melting a plastic wire, a cold material with a paste like consistency is used. The material will be dried by air (Warner et al. 2014, 14).

4.2.3 Polyjet

The Polyjet process is recently added. It uses a liquid photopolymer material but unlike SLA the object is not submerged in resin but it uses a print-head equivalent to that of an Inkjet printer to directly drop the micron-scale droplets of photopolymer on the object. As soon as each layer is accumulated, the liquid on top layer is treated with UV light (Warner et al. 2014, 9).

4.3 Conclusion:

According to my research on different processes and the idea of printing objects at home or in technological booths, I've come to a conclusion that FDM has the most potential for my concept, because these kind of 3D printers are affordable and they provide good print quality. I also got familiar with a FDM named RepRap that increases the building chance of my ideas. In the next part we will talk more about this 3D printer.

5. RepRap

The manufacturing of the low-cost RepRap machine in 2008 has turned the DIY Industry into a new page (Srinivasan and Bassan 2012).

When the second RepRap printer in May 2008 was built it immediately started printing the components to build the third RepRap, and so on. Today over 20,000 RepRap printers exist, which mostly are using components manufactured by other RepRaps (Srinivasan and Bassan 2012).

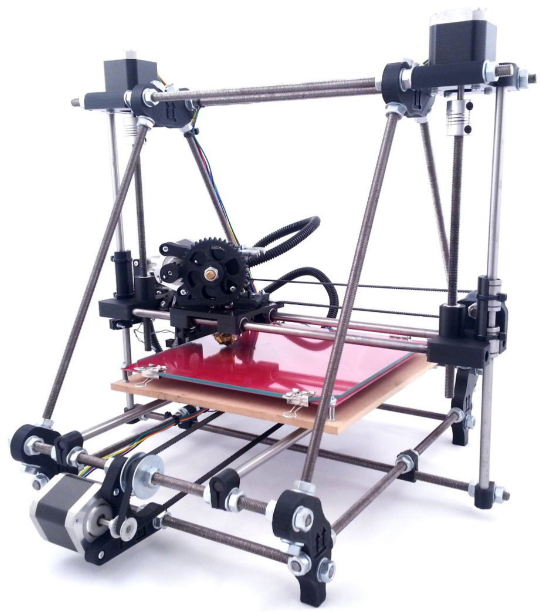


Figure 14 - RepRap

A RepRap machine best suits for individuals or undeveloped countries to build complex products with a low-cost machine. A whole RepRap kit costs about $500.

The RepRap design is inspired by open source software models which means that the design is not secured by any patents and it is open to any Improvements by users.

As a consequence, there is much more creativity in producing RepRap and its deravities compared to other 3D printers. All sort of industrial products will be affected by open source approach, leading to a lean production system in the future (Srinivasan and Bassan 2012).

5.1 Me and The Passion of The RepRap

After researching the various 3D printers and getting to know the RepRap I decided to buy one to become more familiar with it.

The notable point about these sorts of printers is that they come in an unassembled package in which you have to connect all the pieces together and do a bit of programming with an open source software to be able to install the printer. Another challenge is to connect the electronic pieces together and check whether they are synced or not.

The whole experiment was really interesting for me and acquainted me with a little programming and also consulting with electronic engineers about professional phrases to terms and be able to assemble the machine.

Although I haven’t been able to print with these printers yet, I believe that they have the potential to be user-friendly and the market growth it will be easier.

Below you see some pictures of the assembling process of a 3D printer.

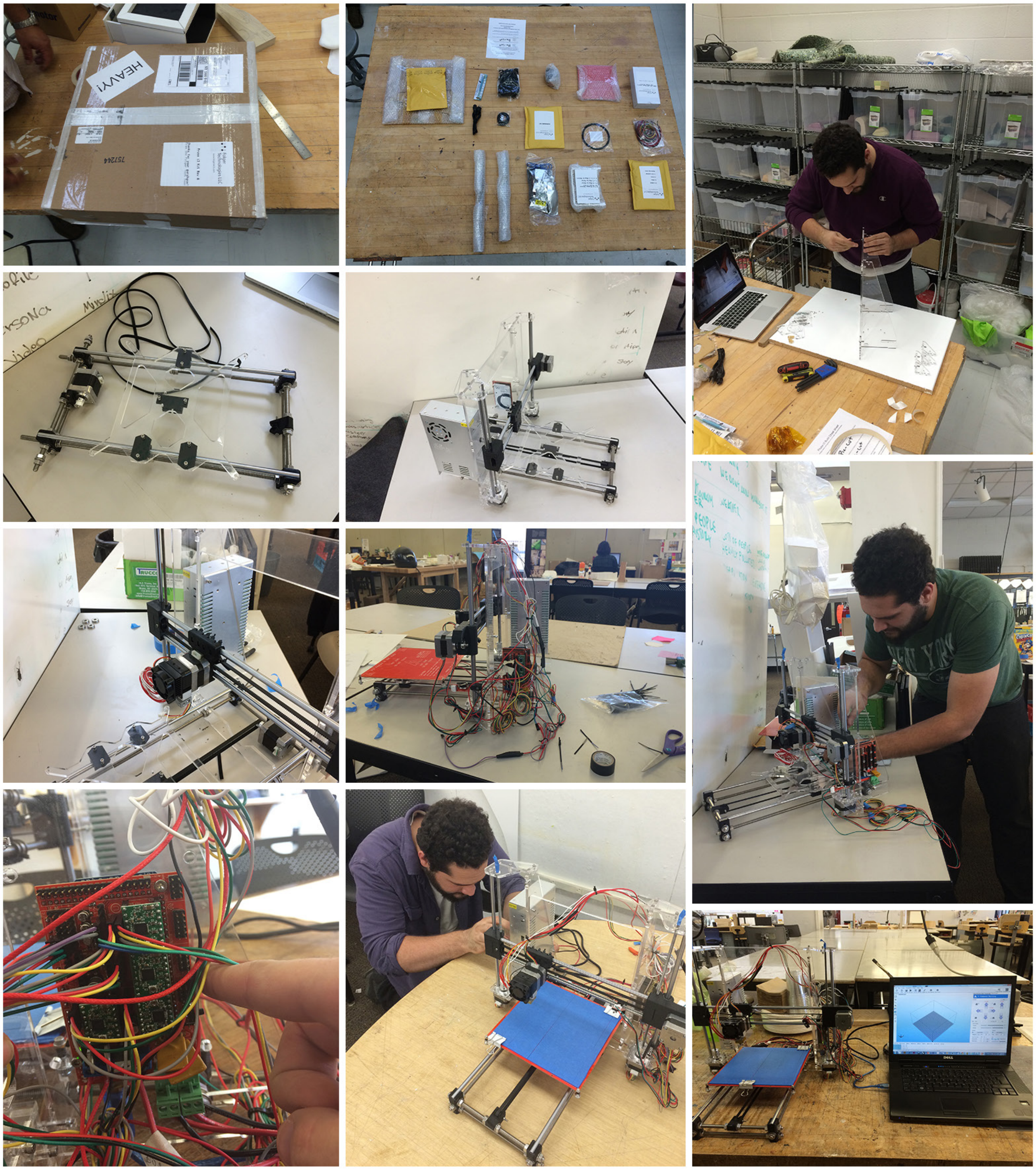


Figure 15 - RepRap assembling processes

6. 3D Printing Materials and Sustainability

Nowadays 3D printing media come in a wide range of materials that are reserved in different states (powder, filament, pallets, granules, resin etc).

Specific materials are now generally developed for specific platforms performing dedicated applications (an example would be the dental sector) with material properties that more precisely suit the application.

On the other hand, nowadays there are various assistant materials from different 3D printer vendors to cover them all.

In the mean time, plastics are the most preferred and common material of them all to use for FDM printers. In the following section we will talk about common materials for 3D printing.

6.1 Materials

6.1.1 ABS

ABS is a flexible, soft milky beige color polymer that can take many forms. The flexibility of ABS makes building interlocking parts or pin connected pieces easy to deal with. ABS is a much more recyclable material rather than PLA (Peels 2011).

ABS is strong, flexible with high temperature resistance which makes it a preferable plastic for engineers and professional users. It requires some heated print beds that not all printers provide (Peels 2011).

6.1.2 PLA

PLA is derived from renewable resources such as cornstarch, sugar cane, or even potato starch.

PLA is used in food packaging, bags, disposable garments and many more. PLA is tough, but a little brittle, once it has cooled down it seems to have higher maximum printing speeds, lower layer heights, and sharper printed corners. PLA is generally considered the easiest material to work with when you first start printing although it is considered hard to work with in some complex interlocking assemblages and pin-joints. PLA can be sanded down or may be painted over with acrylic paint (Chilson 2013).

6.1.3 Laywoo-D3

Laywoo-D3 is a wood based filament (made from recycled wood and harmless binding polymer). The final prints vary by the temperature. It is high at low temperature and dark at high temperature. Objects after printing look and smell like wood. Laywoo-D3 may leave threads behind during non-extrusion moves of the print head (kaziuns 2013, 95).

6.1.3 Nylon

Nylon is easily colored but is hard to use because of shrink/ wrap/ curling problems. It is flexible as thin layers and fine for strong and low friction pieces (kaziuns 2013, 96).

6.1.4 Polyethylene Terephthalate (pet)

Polyethylene Terephthalate is a crystal like, transparent filament which is impact-resistant. By printing thicker layer heights, you get more opacity (kaziuns 2013, 96).

6.1.5 Laybrick

Laybrick is a sandstone-like 3D printer filament. Its print temperature varies from 165C for smooth surfaces and 210 for rougher surfaces (kaziuns 2013, 96).

6.1.6 High Impact Polystyrene (HIP)

High Impact Polystyrene or hips is more developd and also cheaper than PVA and is great for printing final parts. HIPS hide the print lines because of having a great surface finish to them (kaziuns 2013, 95)

6.1.7 High Impact Polystyrene (hips)

High Impact Polystyrene or hips is more developed and also cheaper than PVA and is great for printing final parts. HIPS hide the print lines because of having a great surface finish to them (kaziuns 2013, 97).

6.1.8 Polycarbonate (pc)

Polycarbonate printing demands high temperature nozzle like the Prusa nozzle. This filament is experimental (kaziuns 2013, 97).

6.1.9 Polycarbonate PCL

Polycarbonate PCL also referred to as Makerbot flexible filament, InstaMorph, or Polymorph offers an easy way because of its low melting point (58-60 C) which can simply be heated in hot water and reformed (kaziuns 2013, 97).

6.1.10 Polyvinyl alcohols (PVA)

PVA is used as a support material and dissolves in water. It is expensive and hard to work with (kaziuns 2013, 97).

6.2 Sustainability

As I referred to before PLA is a bio-material and because it is obtained out of natural resources such as corn, potatos or sugar beets, it is acknowledged as an “earth friendly”, dream material. Kristy Boyle also says that , “ While PLA is a bio-material it is also very difficult to recycle.” PLA is a material that with all its benefits it still has the capacity to be improved. One of the most promising is in Loopla a system for recycling used PLA into more PLA. Here it is the Lifecycle of PLA based on Loopa System (Peels 2011):

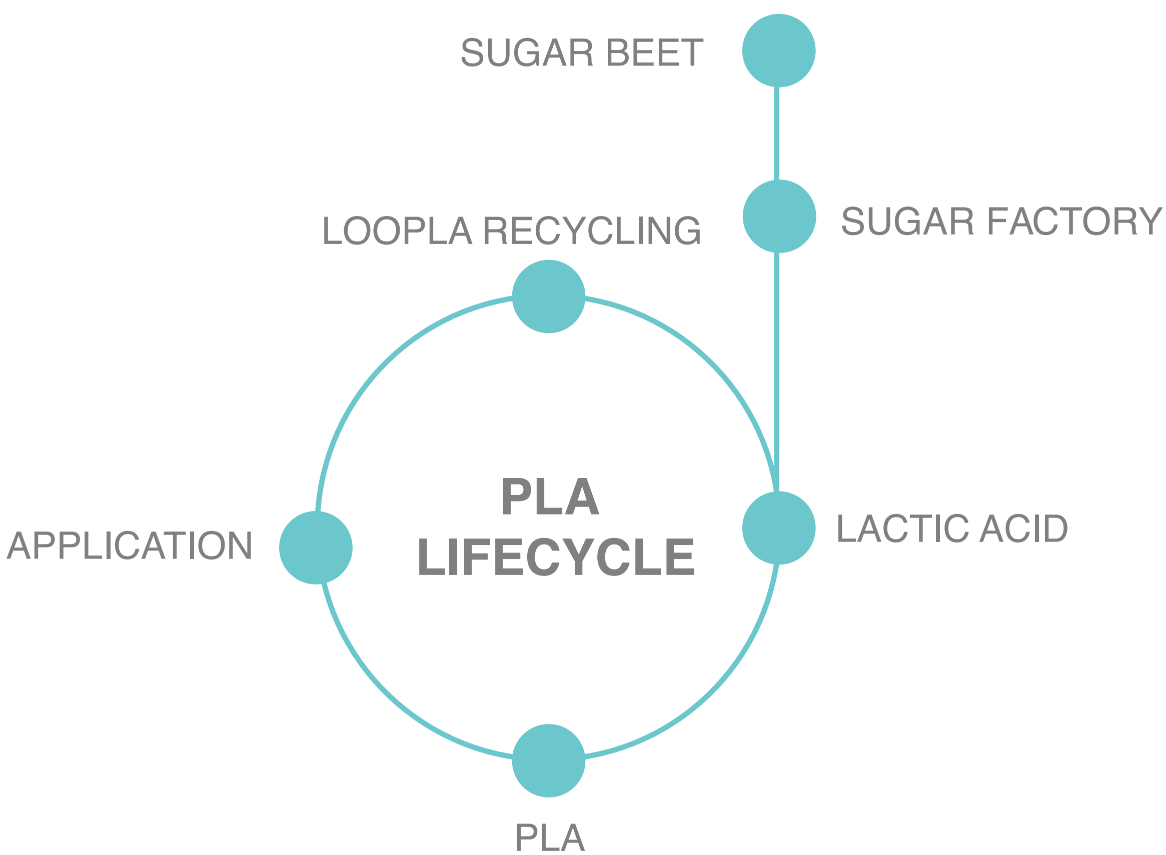


Figure 16 - PLA lifecycle

Accordingly you can use this material over and over and produce many pairs of shoes with the use of only this one material by a 3D printer. Over this method you are able to have a sustainable and earth friendly product.

6.2.1 Filabot

During my researches about 3D printing materials and how to recycle 3D printed products I got familiar with a product called Filabot.

Base on Filabot ability, it is possible to feed cut-up plastics to the machine which melts them and force out the remaining ones into strands of material for usage in a 3D printer. The Filabot can handle plastic chunks up to 3-inches square and will extrude plastic strands in either 1.75-millimeters or 3 millimeters in thickness which are standard sizes for 3D printers (Tofel 2013).

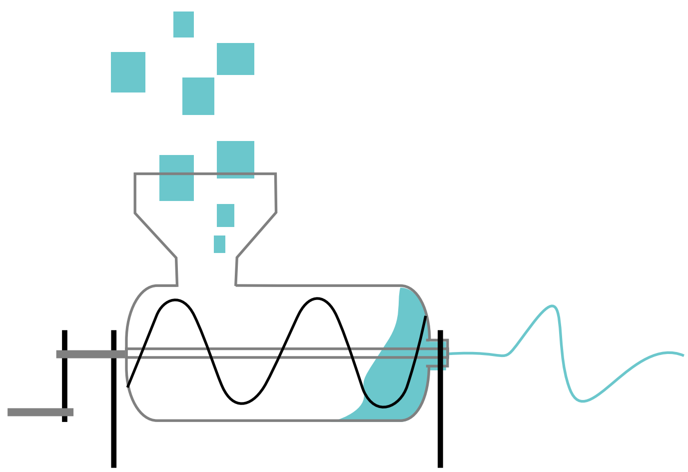


Figure 17 - Filabot mechanism

Each Filabot costs about $500. And a filament for each final printing layer is prone to diminish quickly (Tofel 2013).

So a machine which creates its own filaments would be long term money saver. It is also acceptable to use plastics at home for printing. Actually if a 3D printed model doesn't come out appropriately you can recycle it with a Filabot and print an accurate object (Tofel 2013).

7. 3D Printing Global Effects

7.1 Global Effects on Manufacturing

The nature of 3D printing technology is already changing the way products are manufactured and is giving new ways of thinking in terms of social, economic, environmental and security implications of the industry process with favorable global impact (3dprintingindustry 2014).

This statement declares that 3D printing has the potential to bring production closer to the end user and/or the consumer, thereby decreasing the current supply chain limitations. The customization value of 3D printing and the ability to produce small production batches on demand is a way to engage costumers AND decrease or neutralize inventories and stock piling — something similar to how Amazon operates its business (3dprintingindustry 2014).

By possibly printing the spare parts on site, shipping them from a part of the world to another can become obsolete. This can be quite a challenge on the way small or large businesses, the military and the consumers interact universally. But the ultimate purpose is for individuals to print their desired objects at home (3dprintingindustry 2014).

Now with 3D printers , various geometries and impossible shapes can be created and most importantly, experts believe thant 3D printers have the potential to grow into innovation and bring back the forgotten local manufacturing (3dprintingindustry 2014).

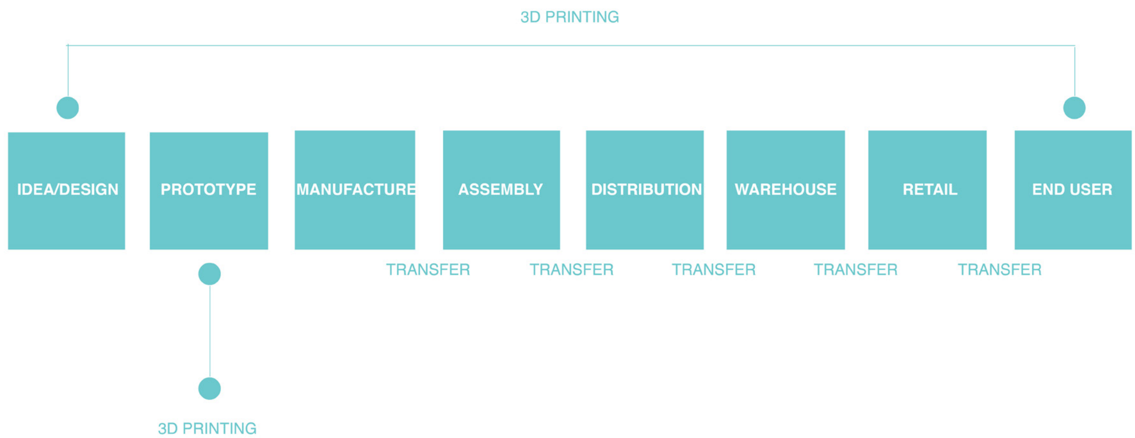


Figure 18 - The long-term opportunity for individuals

7.2 Potential Effects to the Global Economy

3D printing technology has effective potential universally. The change of production and distribution from the current model to a localized production based on-demand, on site, customized production model could potentially decrease the ongoing imbalance between export and import countries (3dprintingindustry 2014).

3D printing can develop to a vast industry even providing brand new professions. The profession varies from product designers, print operators, and material suppliers to intellectual property legal disputes and settlements. Piracy is a current threat to 3D printing.

3D printing has its advantages and disadvantages. For instance it has lowered manufacturing cost through recycled and other local materials. But the loss of manufacturing jobs could hit many developing countries severely, which would take time to overcome (3dprintingindustry 2014).

CHAPTER 6.
DESIGN

1. Purpose of Design

The purpose of this project is to develop a range of design concepts for printable footwear. The idea is to build a consumer-based system, which reduces labor for manufacturing and provides ease of access to new products for consumers.

Experts predict that everyone will have a 3D printer at home in near future and people will be able to design and make objects on their own in the near future (Dale Nicholls 2014).

Currently the 3D printing technology is not developed enough for non-designer use. By developing a range of stylish footwear design concepts to be made with 3D printing technology, the production process would speed up and the costs of production would be reduced. This idea will allow everyone to use these prepared designs and print usable products on their personal 3D printers.

This footwear will be designed in a way that lets a regular 3D printer make it without any fail. In addition, the final CAD files of products will be accessible to 3D printer owners.

2. User Research

2.1 Design brief

During my research I started focusing on user's needs and demands; Based on that, I began providing a Design Brief. An inclusive brief is essential for designers to track down their work process. In the brief, I tried to strike a balance between providing the right information and try not to limit my creativity. Therefore, I prepared a checklist including marketing issues for the collection:

– Brand equity: who is my client, what are the client's brand identity and position in the market?
– Brand positioning: what kind of shoes are customers of the client's brand looking for?
– Target market positioning: what is the value of the product (e.g. price range)?

In the brief I will list information about customer characteristics, such as their age, status, professional profile, lifestyle preferences and purchasing power. It will often set a budget for the collection.

2.2 Persona:

NAME: KATE

AGE: 26

OCCUPATION: FASHION JOURNALIST

SOCIO-ECONOMIC STATUS: MIDDLE CLASS / UPPER MIDDLE CLASS

INTERSTS: FASHION MAGAZINES, DESIGN, YOGA AND ART EXHIBITIONS

Figure 19 - User profile

3. Mind map

According to my research, finalizing my users, and finding the perfect technology, I have designed this mind map to see how do data matches and how I can use these keywords in my final design.

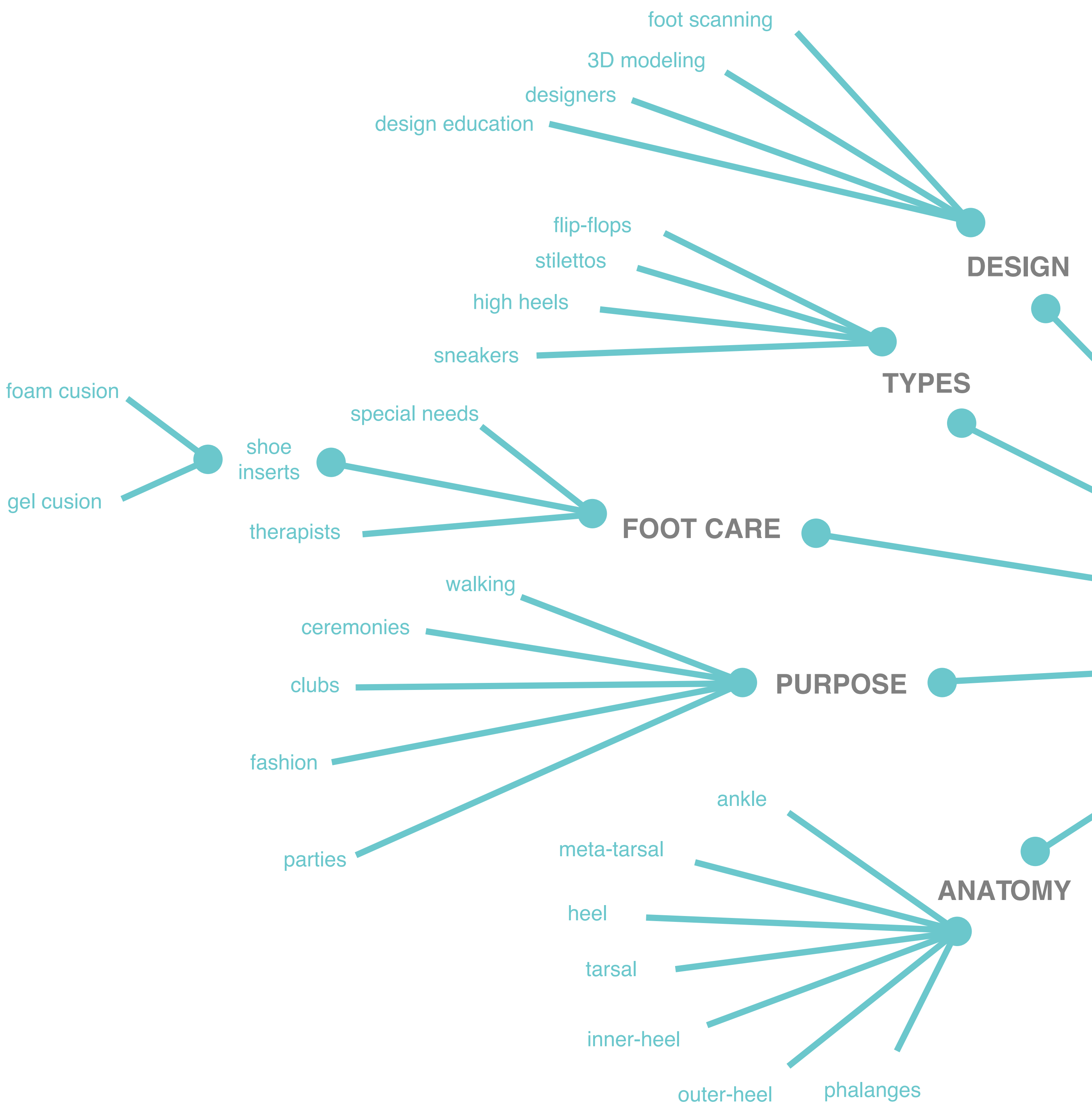
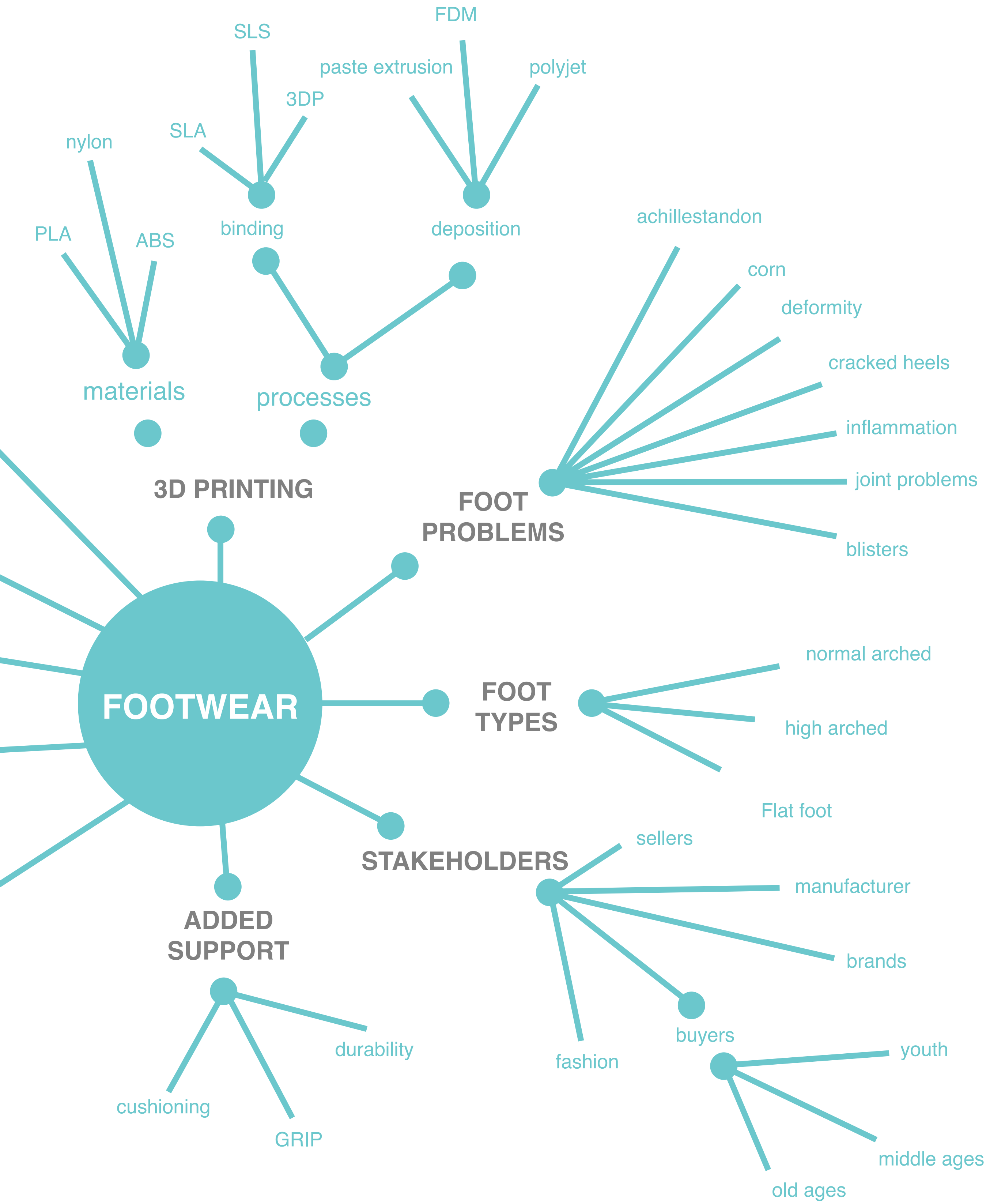


Figure 20 - Footwear mind map


FOOTWEAR
3D PRINTING
materials
PLA
nylon
ABS
processes
binding
SLA
SLS
3DP
deposition
paste extrusion
FDM
polyjet
FOOT PROBLEMS
achillestandon
corn
deformity
cracked heels
inflammation
joint problems
blisters
FOOT TYPES
normal arched
high arched
Flat foot
STAKEHOLDERS
sellers
manufacturer
brands
fashion
buyers
youth
middle ages
old ages
ADDED SUPPORT
durability
cushioning
GRIP

4. Ideation

4.1 Sketching

Ideation began with discovering inspiration with pictures, and mind map. Later came sketching to help finding possible shape, function, and aesthetic.

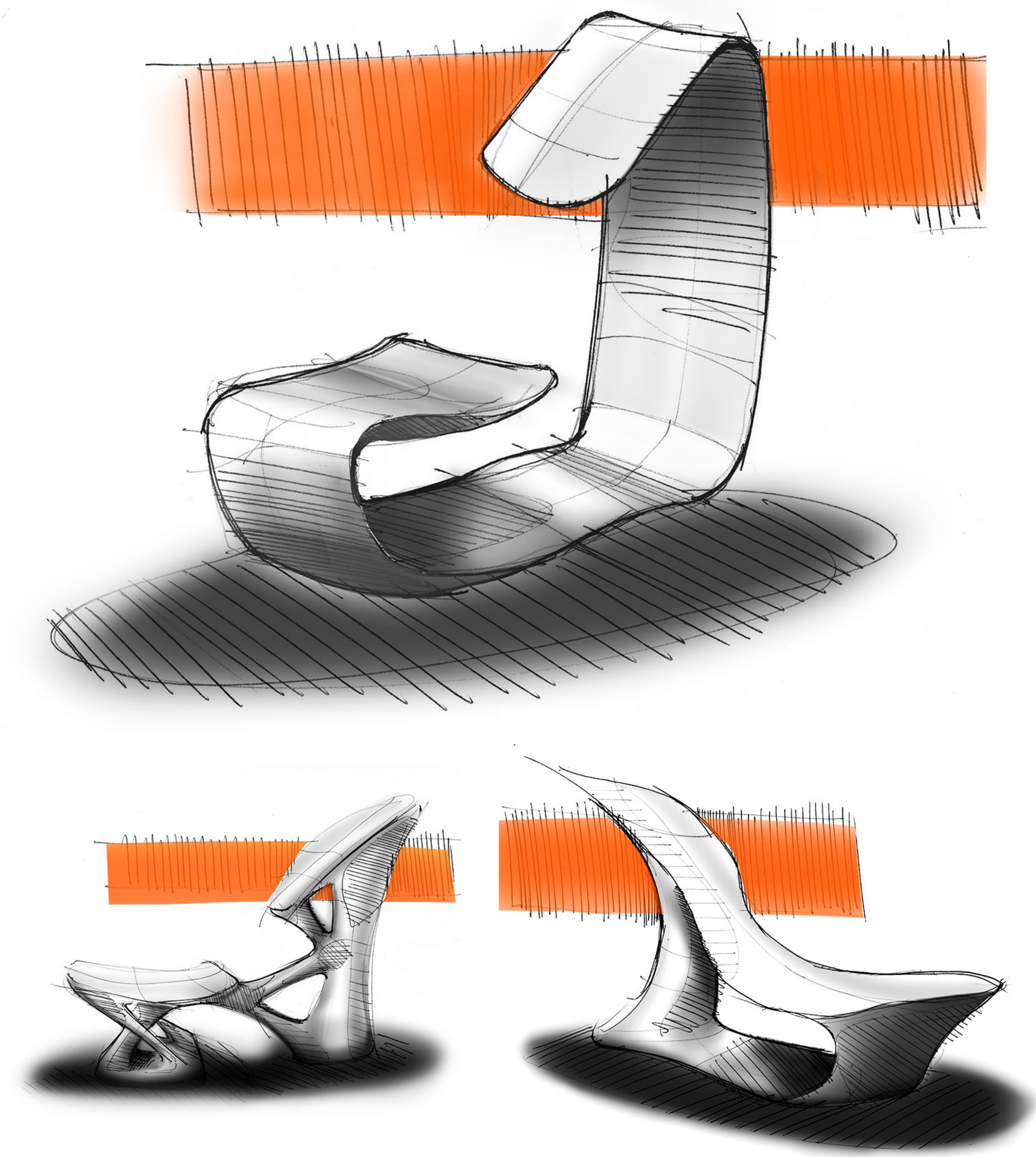


Figure 21 - 2D ideation 1/2

Figure 22 - 2D ideation 2/2

4.2 3D modeling

After finalizing my raw ideas I started to make them three dimensional with Autodesk 3D's MAX software to be able to use them in 3D printing process.

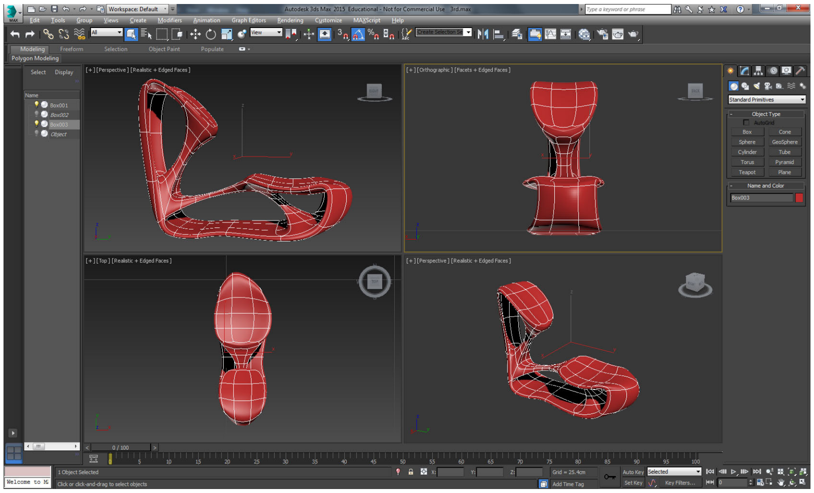


Figure 23 - 3D modeling with 3D's Max

The reason I chose 3Ds MAX was that this software can modeling organic forms better which best suits my stylish and organic design ideas.

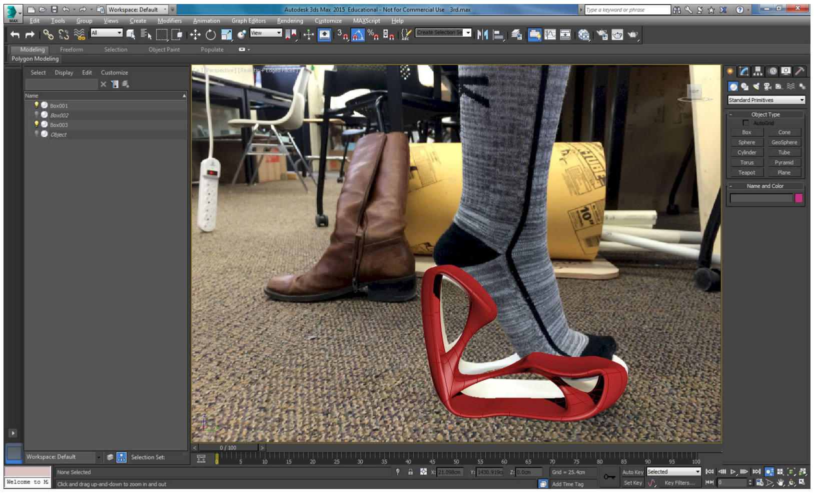


Figure 24 - 3D modeling by photo

For every user I took pictures of their feet from different planes and imported them in 3D modeling software so I could make the shoes' model similar to their feet. This leads the product to be ergonomically suitable for everyday use.

4.3 3D printing

In this stage I have exported 3D files with STL format and uploaded them to 3D printers. I used 2 different 3D printers for printing:

4.3.1 MakerBot Replicator 2X

With this printer I used ABS material in two different colors. But I confronted two limitations. The biggest one was that I wasn't able to print a shoe size bigger than 6.5. And the other one was the printing time. The time spent on printing "shell" and "infill" could go up to 30 hours.

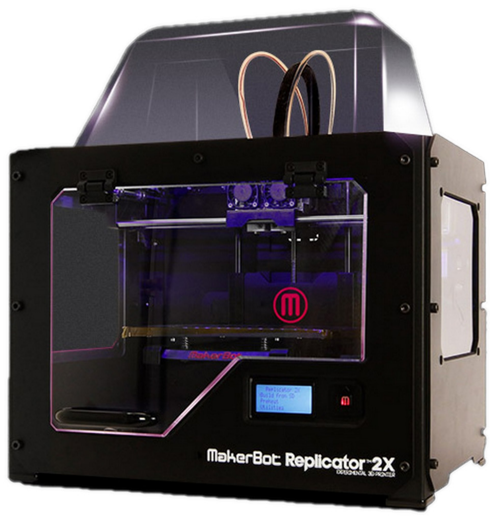


Figure 25 - MakerBot Replicator 2X

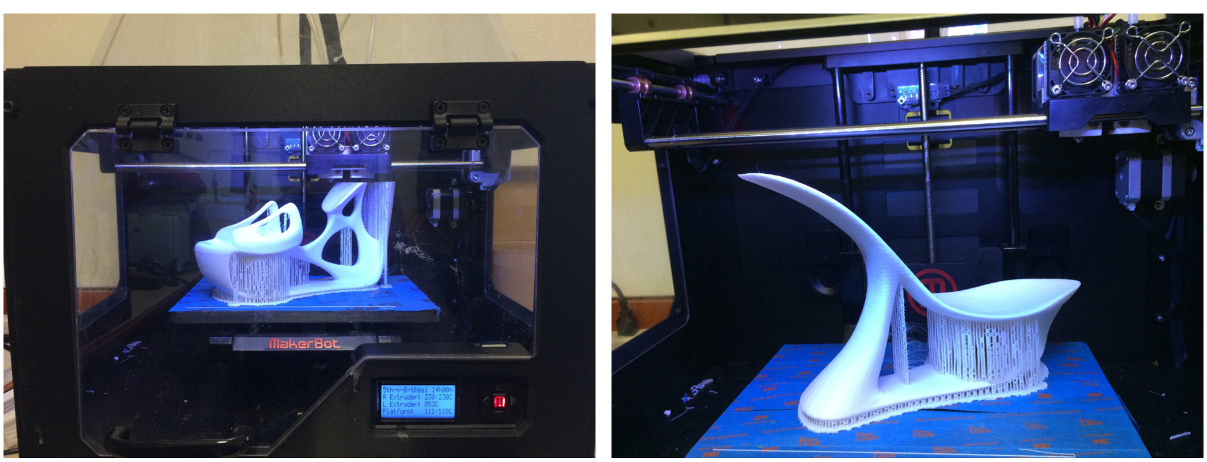


Figure 26 - 3D printing with MakerBot Replicator 2X

4.3.2 MakerBot Replicator 5th Generation

With the makerbot replicator 5th generation I printed PLA. Also due to giving more space I was able to print a size 8.5 and read the model on the plate printer. I had rotated the 3D file 90° before sending the file to 3D printer. With this method print's layers were pressurized on opposite directions which would result in shoe's more resistance against user's weight.

Figure 27 - MakerBot Replicator 5th Generation

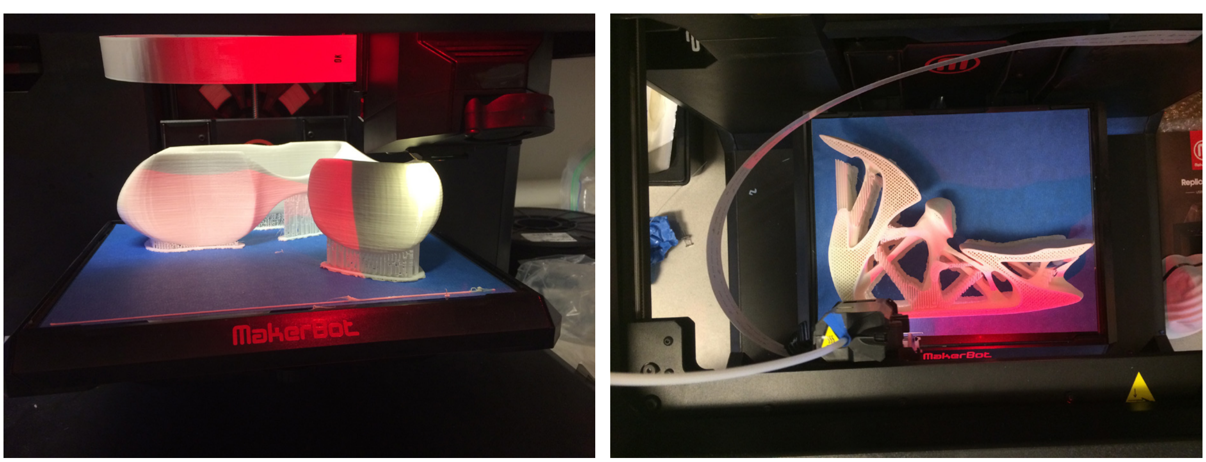


Figure 28 - 3D printing with MakerBot Replicator 5th Generation

5. User testing

After printing the shoes I asked different people to try them and give me feedback on the style and ergonomics to improve my concept on next designs. It was during this time that with the help and consult of a mentor I came to a conclusion that it is better to use a special trait of a 3D printer that is the potency of producing objects with unconventional forms that are almost too hard to be built with common manufacturing systems.

Therefore, according to my interest and searching for a stylish form, I tried to approach organic forms.

Below you can see some of the stages:

Figure 29 - 3D ideation & user testing

6. Developing Idea

The next challenge after finalizing the basic part was how to connect the upper and lower parts. I tried different methods such as straps or pieces that would print with the base part and would hold the shoe to the foot. In some cases the pieces weren't strong enough and in some the foot wouldn't fit in the shoe. Finally I came up with 2 concepts which I will explain later. Below I show the idea development.

Figure 30- Developing the idea

6. Final design

Figure 31 - Final concepts - ATOSSA concept 1

Figure 32 - Final concepts - ATOSSA concept 2

8. Design features

8.1 Ergonomics

Ergonomics is one of the most important factors in a shoe. Given that we have a 3D file of the shoe, we are able to print the final product later using this file, so that by using 3D scanning technology or photographing different angles of foot and putting them in 3D software, we can edit the 3D file and adjust all the unique traits of user's foot to the final product. In fact, the printed shoe is unique to the user. This trait improves user's foot health and comfort.

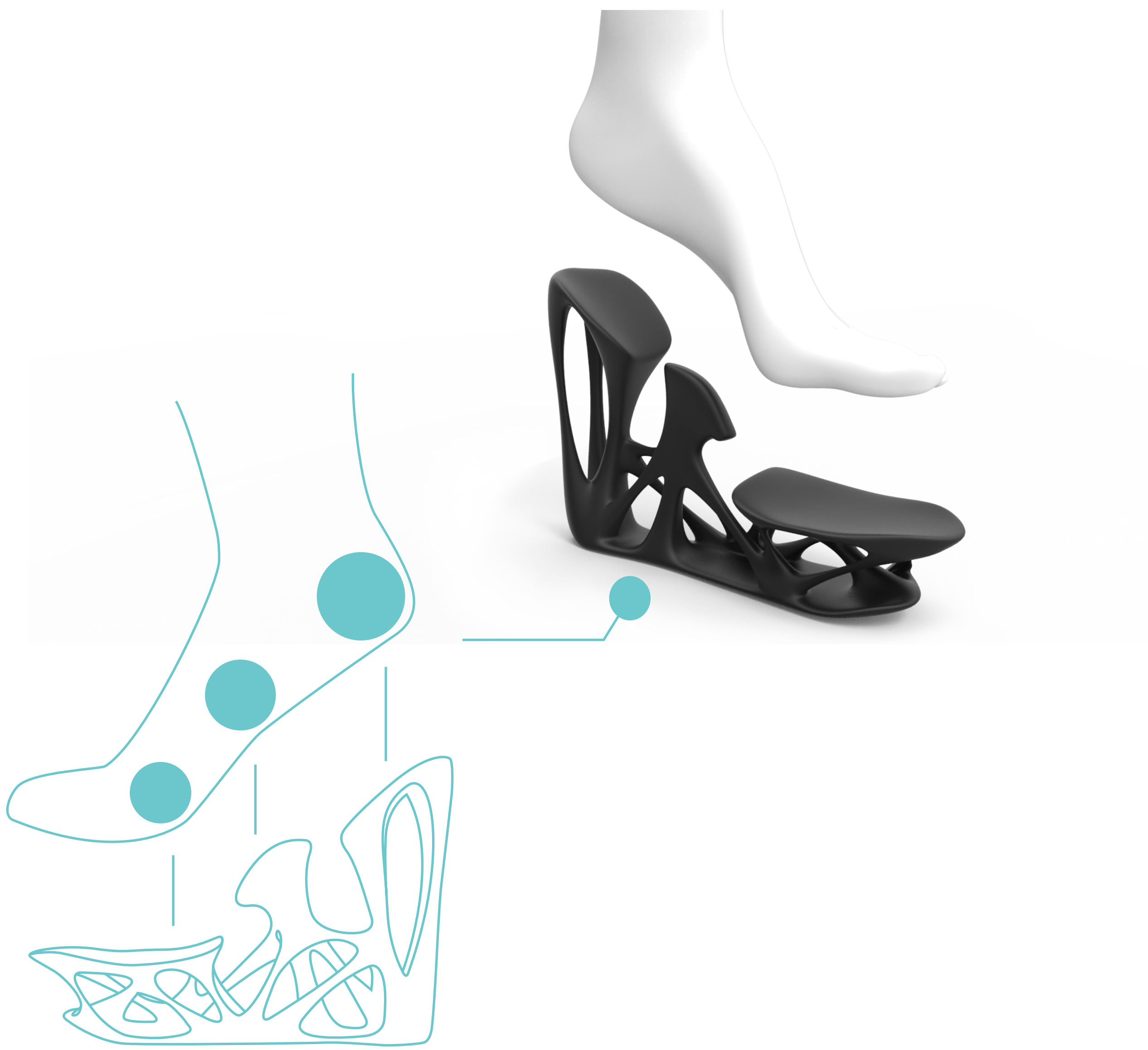


Figure 33 - ATOSSA ergonomics features

8.2 Style

After trying many methods, I came up with 2 concepts. One is using “strap” and the other one is to print whole parts together so there is no need to assemble any additional parts.

Strap:

This is a more casual idea in which the users are able to use different strap models and textures with their own taste or even tie them in the ways they wish to.

Although these ideas needed to be more developed and sometimes during the user testing the strap became loose or fell but it was pretty acceptable to use.

Print whole parts:

This idea had a more classic style and there was no need to add or assemble any more part to the shoes, making ready to be worn after printing.

This model was more efficient than the one with straps. On the other hand, it needed a lot more time in preparing the 3D file and demanded considering more factors. If any part of the shoe is damaged it needed to be changed fully. According to the tests I performed, it had an acceptable strength.

Figure 34 - ATOSSA styles

8.3 Structure

As I explained before in the ideation section I was searching for a stylish and organic structure to be able to show 3D printing's ability in producing more complex objects. Also I was searching for a powerful structure that could handle my user's weight.

According to this, I searched for different structures and patterns until I saw the microscopic texture of bones, Which presents both style and power.

Therefore I rearranged textures according to the points that had the most pressures in the shoe, such as Ball, Hill, and Arch.

With this structure I can target many audiences and get helpful feedback from them about style and structure. This trait distinguishes my shoes from others.

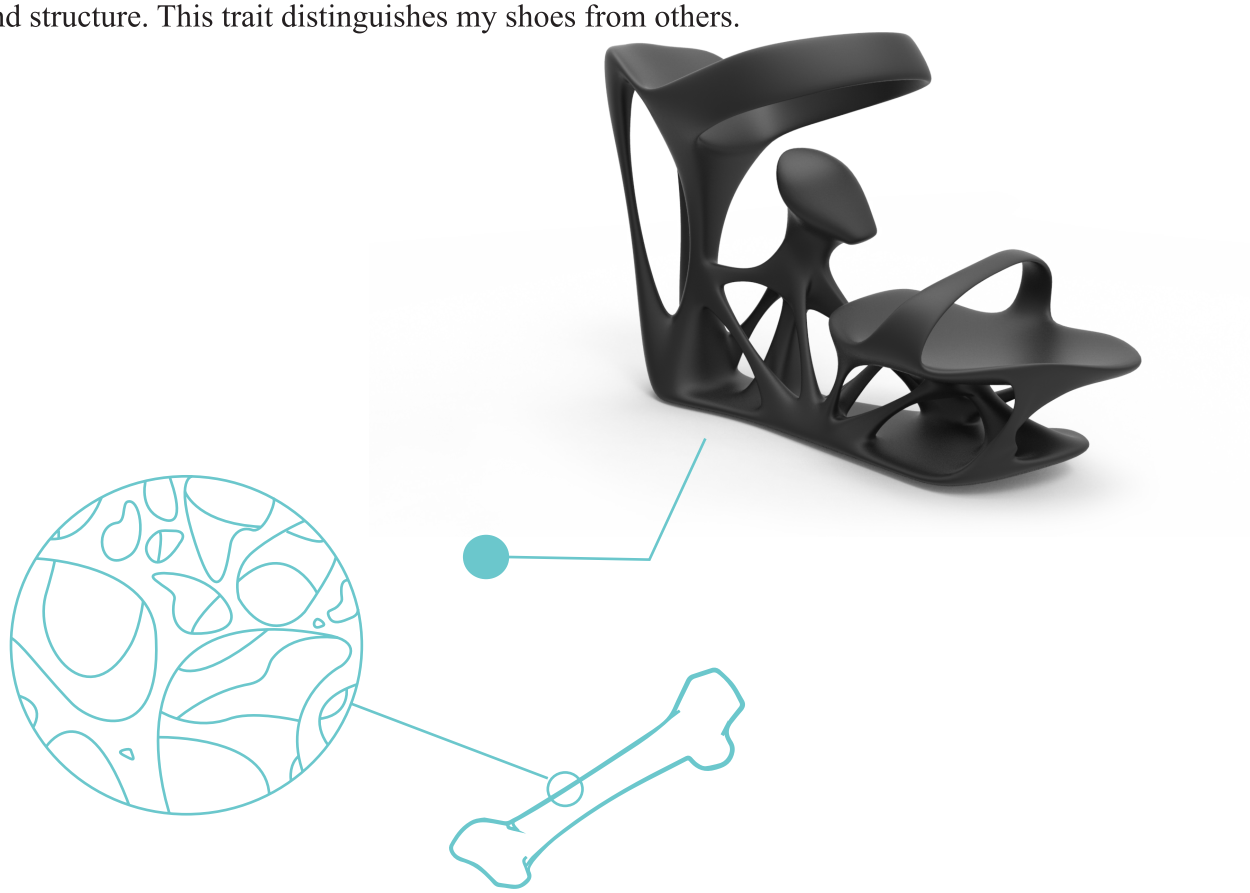


Figure 35 - ATOSSA structure

8.4 Life Cycle and Sustainability

A shoe basically contains 15 to 50 parts. With 3D printers it has decreased to 1 to 4 parts which can save a lot of resources such as money, time, and labor.

On the other hand considering PLA's other traits and Filabot technology which I explained about in the 3d printing chapter we can define the product's life cycle with the methods seen on the diagram below:

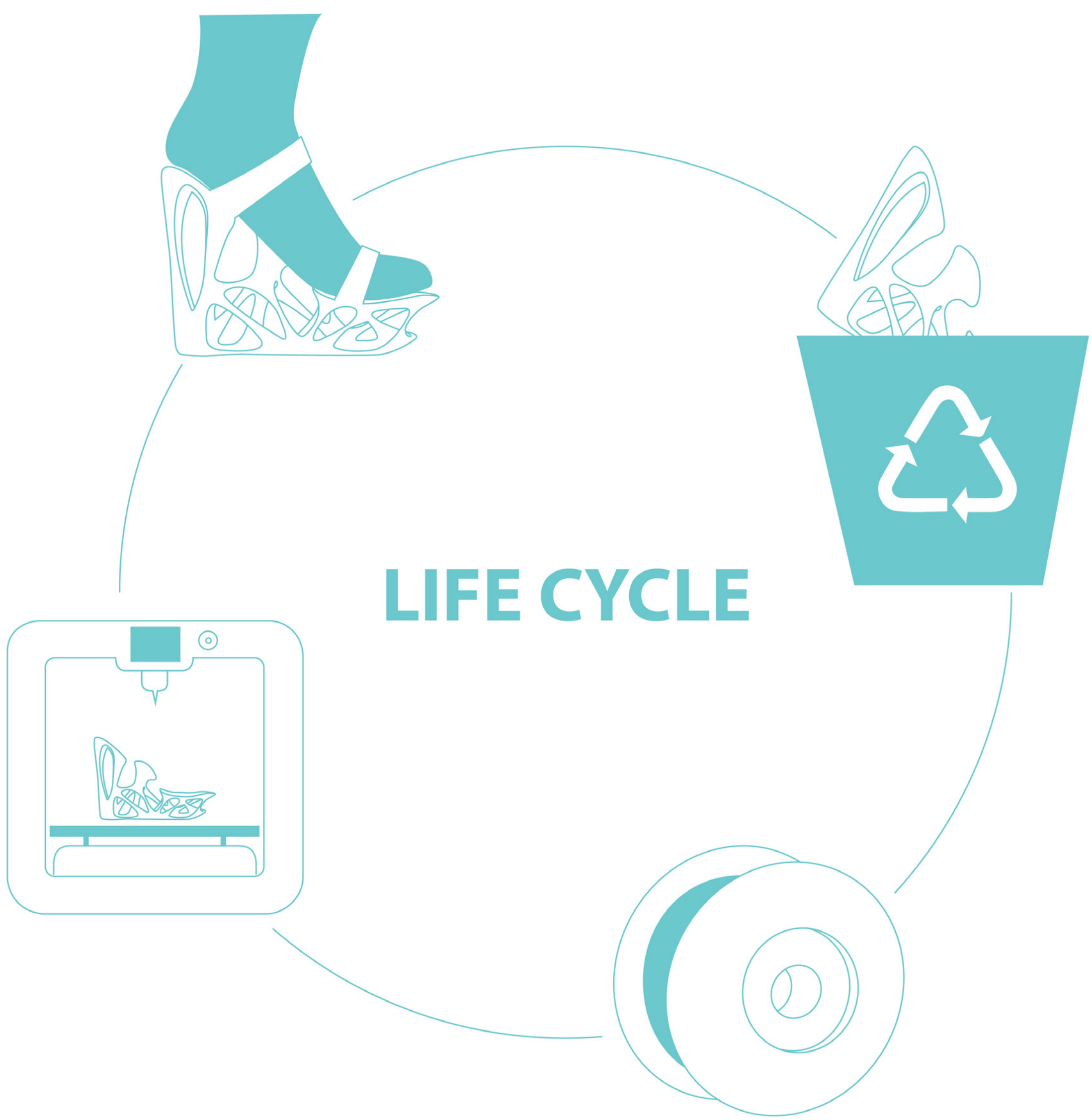


Figure 36 - ATOSSA lifecycle

9. Service Design:

This product is different both in terms of production and presentation. The product is technological and has its own special users.

Here with 3 different concepts I am showing users ways of access to the product. These stages must later be tested in more research to help us find a more efficient concept.

9.1 Concept 1:

In this concept users both edit and print the files on their own.

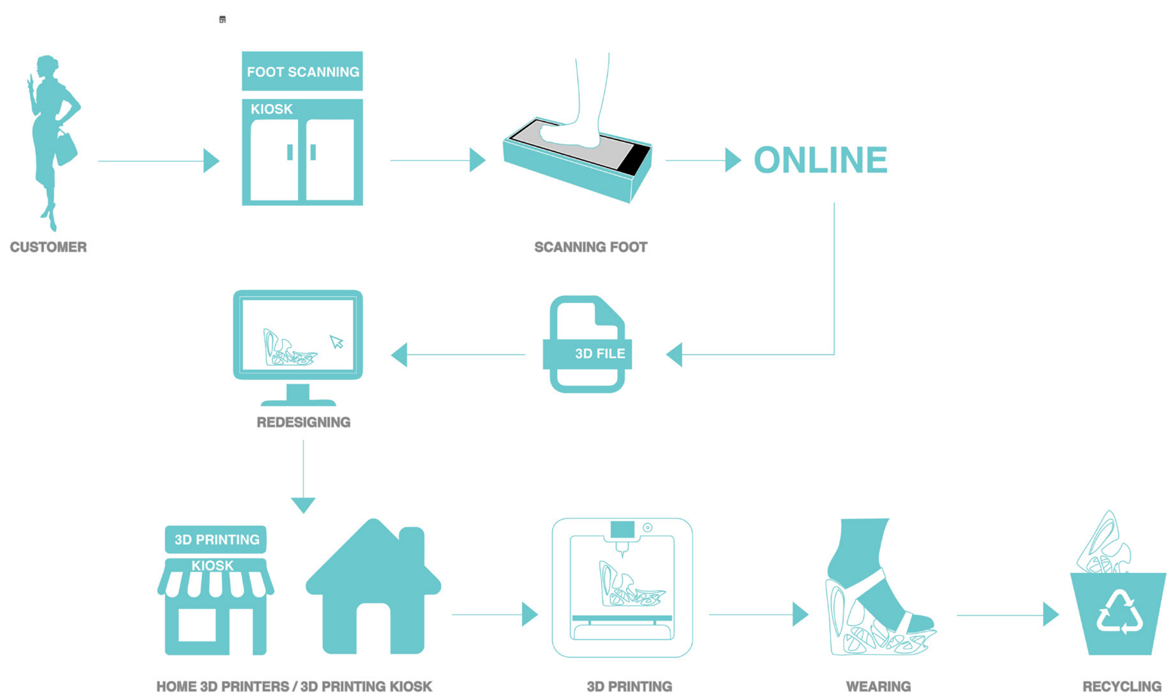


Figure 37 - ATOSSA service design – Concept 1/3

9.2 Concept 2:

In this concept, users only get help from the designer for editing and later can benefit from the 3D printing booths on their own.

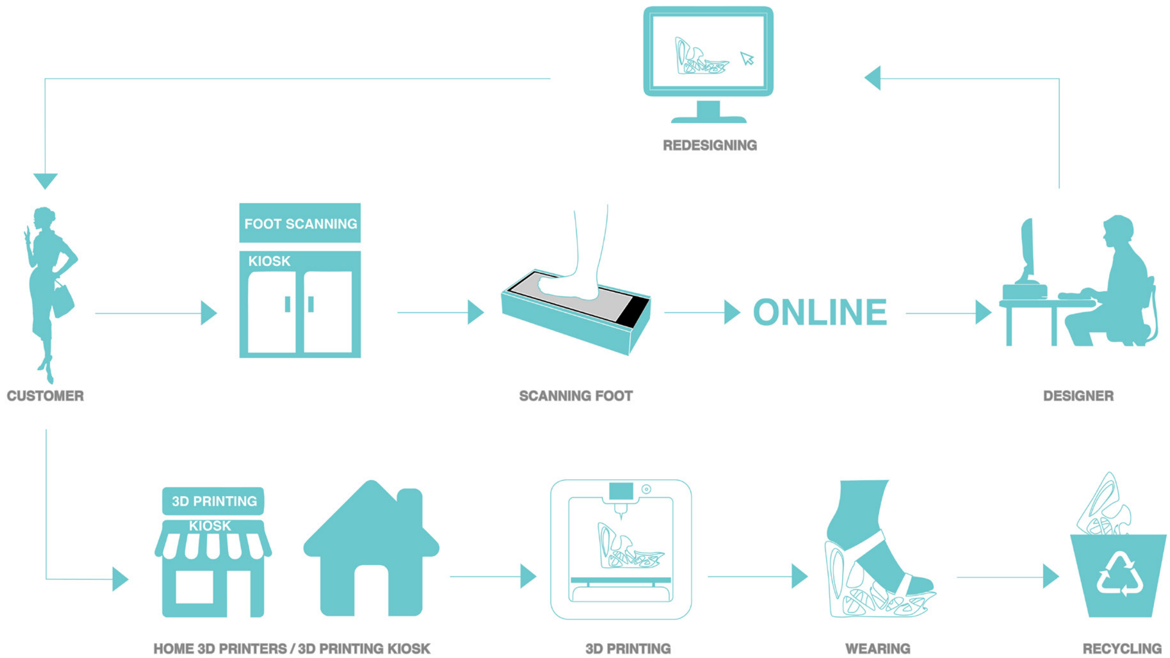


Figure 38 - ATOSSA service design – Concept 2/3

9.3 concept 3:

In this concept users go to a store and the employers do all the stages to finally give the user the final product, ready for use.

Figure 39 - ATOSSA service design – Concept 3/3

CHAPTER 7.
Conclusion and Further study

1. Conclusion

The world today is glued to consumerism. People are looking for brand new products everyday and are eager to experience new things. This Infinite desire to always see new objects and products results in a short useful life of a product. On the other hand, users get more selfish day by day and are in search for self- customization.

Designers perform the biggest part in creating and showing user's needs with the products. Therefore I believe that designers must know their surroundings and user needs. on the other hand they must be in constant search for new technologies and check to see how they can give a certain direction to consumerism and find an innovative way to confront it.

I tried to decrease production cost and time spent in designing products as a designer and ease the way of producing. I mostly tried to focus on user's needs and to produce more earth- friendly objects.

In the end it is not far to say that Atossa is a result of my interest for 3D printing technology. A technology which soon will be the guest of our house and can be used, daily. Therefore it would be the best if it can be used in a maximum way. Atossa shows this potential with a product used in our everyday life.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2. Further Study

Shoe is a complex product and in designing it, many factors take part which needs great the factors of time to deliver a perfect design. Therefore I must research more on the factors below:

Ergonomics:

I need to focus more carefully on this part for next stages of designing and get to know more and more on foot anatomy and its character. Then maybe I will be able to design more medical shoes which benefit health even more.

Foot sacnning technology:

At the moment my method to adjust shoe and foot, is to take pictures of feet from different angles. In further steps I must focus more on the technology and observe how I can apply related devices with this product.

User testing:

Until now I had limited time. But for user testing I need to interact with them more and get more feedback on different shoe aspects like ergonomics and style.

Different styles

With upcoming improvements on materials and 3D printers I can design different types and styles of shoes and print them.

3D printers and materials:

With the remarkable improvements that this technology and its related materials have I must study more and see how I can increase the quality of products and how to ease production. Print timing has been a problem until now but I hope that with technology improvement I can decrease production time even further.

CHAPTER 8.
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